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AN INVESTIGATION INTO THE EFFECTS OF PROCESS VARIATION IN THE BASE PROCESSING SEGMENT OF THE DEPOT-LEVEL REPARABLE PIPELINE

THESIS

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Logistics Management

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The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

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Abstract

The purpose of this study was to identify and provide pipeline managers with the knowledge and tools necessary for reducing process variation associated with retrograde asset flow time. Several Air Force studies have been devoted to researching portions of the pipeline process. Our study continues this trend of investigations by studying the Base Processing Segment.

This study demonstrates the potential for analyzing the Base Processing Segment of the depot-level reparable pipeline using Statistical Process Control (SPC). Retrograde asset flow time data collection methods and current management practices were examined. Control charts were used in the passive mode to analyze and determine the statistical stability of the Base Processing Segment. Control charts were used in the active mode in an one-factor experiment that demonstrated the techniques for continuous improvement.

Control charting can improve managerial efforts to reduce the flow time of assets through the Base Processing Segment. In this study, elimination of Assignable Causes of variation reduced average flow times by 31 percent. Thus, identifying and eliminating Assignable Causes of variation can immediately improve process performance. The subsequent removal of Common Causes of variation will improve the process.

AN INVESTIGATION INTO THE EFFECTS OF PROCESS VARIATION IN THE BASE PROCESSING SEGMENT OF THE DEPOT-LEVEL REPARABLE PIPELINE

I. Introduction

General Issue

The United States Air Force (USAF) and the Department of Defense (DoD) face a challenge to incorporate modern management practices in preparing for the 21st century. Without the threat of a superpower confrontation, competing national priorities tempt our country's leaders to draw financial support away from defense spending. The DoD budget request (adjusted for inflation) for 1993 is 7 percent below the 1992 appropriation by Congress. Projecting a 4 percent annual reduction through 1997, experts place the DoD budget on par with 1960. The effect on the USAF is a 1993 budget (also adjusted for inflation) 34 percent less than in 1985 (23:355).

In 1989, the U.S. Secretary of Defense published the Defense Management Review Directive (DMRD) which set a target for reducing defense department expenditures at over $30 billion by 1995. Mandatory reductions in supply system costs are specifically addressed in DMRD 901 (1:53). An inventory comprised of 2 million items and valued at over $25 billion, the USAF logistics pipeline is a substantial target to focus on for cutting supply system costs (11:34). A conceptual model of the USAF logistics pipeline developed four subsystems: acquisition, disposition, base-level, and depot-level (3:3). The depot-level subsystem of the USAF logistics pipeline is also known as the depot-level reparable pipeline. Experts estimate that a one-day average reduction in the depot-level reparable pipeline will produce inventory cost savings of approximately $50.9 million (23:14). In 1990, HQ AFLC estimated that the current depot-level reparable pipeline time is approximately 58 days (20:3). Identifying improvements to the depot-level reparable pipeline could be the key to meeting this inventory reduction.

Background

USAF Logistics Pipeline. The USAF logistics pipeline is an immense system which encompasses all of the activities necessary to sustain a war-fighting capability (3:1). Considering the enormous scope of the USAF logistics pipeline, trying to study it as a single process would be ineffective at best. Therefore, numerous Air Force studies have been devoted to breaking up this large system into smaller, functionally oriented segments. In 1989, Bond and Ruth identified four main subsystems that make up the Air Force logistics pipeline:

(1) The base pipeline subsystem

(2) The depot pipeline subsystem

(3) The acquisition subsystem

(4) The disposal subsystem

Breaking these subsystems down further, Bond and Ruth state:

> Each of these subsystems are composed of smaller elements which will be referred to as components of the subsystems. The primary subsystem components are supply, maintenance, and distribution. When considered as a group, these subsystems and their components make up a pipeline. (3:3)

This identification of the four main subsystems led to a follow-on study in 1991 in which an enhanced conceptual model of the reparable pipeline was developed.

Depot-level Reparable Pipeline. Kettner and Wheatley, in their 1991 Thesis, "A Conceptual Model and Analysis of the Air Force Depot Supply and Maintenance Pipeline for Reparable Assets", defined the reparable pipeline in greater detail than Bond and Ruth. Their enhanced conceptual model of the reparable pipeline was divided into six major segments:

(1) Base Processing

(2) Reparable Intransit

(3) Supply to Maintenance

(4) Shop Flow

(5) Serviceable Turn-In

(6) Order and Ship Time

This model provided the necessary documentation and detail to facilitate further research toward improving the pipeline (13:117).

Base-level Reparable Pipeline. According to Kettner and Wheatley, a reparable asset enters the pipeline at base-level. This occurs when the maintenance activity responsible for repairing the spare part determines that they cannot repair the part. At this time, maintenance turns the defective part over to the supply activity for a replacement part. Base supply processes the necessary turn-in and shipment paperwork, and turns the property over to the base transportation function for shipment to the appropriate repair depot (13:117-154).

The most comprehensive study of the reparable pipeline at base level was conducted by the Air Force Logistics Management Center (AFLMC) in January 1991. AFLMC's study objective was to:

> Describe the process and systems associated with the base-level components of the recoverable pipeline. Analyze the pipeline time values for each of the components. Recommend changes in the pipeline process that will reduce the overall time. Recommend changes in the way pipeline time values are collected, calculated and passed to the D041 [The Recoverable Consumption Item Requirements System]. (27:5)

AFLMC identifies the base-level components of the reparable pipeline as base repair cycle time, base processing days, reparable intransit days, and order and shipping time. This definition is much larger in scope than Kettner and

Wheatley's. However, AFLMC's base processing days component is identical to Kettner and Wheatley's base processing segment.

Using data from six Air Force bases, AFLMC was able to measure the flow of reparable spares at base-level. Because the average base processing time was 5.2 days, which met the D041 standard of 6 days, they did not recommend any changes in the existing standard for base processing time. However, they did note one significant finding that applies to base-level as well as all other segments of the pipeline:

> In the course of our study, we found knowledgeable and concerned technicians and managers at all levels for individual components of the pipeline. It became apparent, however, there was little or no centralized knowledge, much less control, of the whole pipeline process. What is lacking is breadth of knowledge and a systematic approach to decision and policy making which crosses the boundaries of the various segments. (27:33)

This finding suggests a need to continue studying the reparable pipeline. However, the question should not be whether reparable items meet D041 flow times, but whether the reparable process is under statistical control (discussed later) and can be improved.

Pipeline Control. Reducing the variation in the time that goods are in a pipeline reduces safety stock levels. Reducing safety stock levels saves money. Savings result because the same level of customer service can be attained with fewer inventory dollars (19:13). Unfortunately, improvements will not result until managers understand how the pipeline works. According to one expert, understanding how the pipeline works will only be possible after the process is defined:

> When a set of activities is not managed as a process, managers face several undesirable consequences. Among them:
>
> 1. A lack of visibility and understanding of how the total process really works.
>
> 2. An inability to access its effectiveness.
>
> 3. An inability to achieve true control of the operation. (17:397)

Kettner and Wheatley found that "The logistics pipeline evolved over the years with no clear understanding or direction of what the ultimate goal was" (13:20). This finding, coupled with Silver's conclusion: "...there is little or no centralized knowledge, much less control, of the whole pipeline process", demonstrates that the pipeline is not in control and its process is not defined (27:33).

When the pipeline is in statistical control, its processes can be improved. Wheeler and Chambers state:

> Being in statistical control means that the variation present in the product stream is consistent over time. Such a process will continue to produce nothing but good product hour after hour, week after week, as long as it remains in control. Clearly this would be an ideal state for any process. (29:13)

Kettner and Wheatley found that the current pipeline control method uses mean times without any consideration given to process variance. They collected data for each segment of the reparable pipeline and found significant variance present. Kettner and Wheatley concluded "...these variances could indicate some processes are out of control" (13:212).

In their AFIT thesis "Planning and Enhancing the Depot-Level Processing of Exchangeable Assets with a Vision Toward the Future", Benson and Hession used Statistical Process Control (SPC) to measure and chart variation in four segments of Kettner and Wheatley's conceptual model of the depot-level reparable pipeline: Reparable Intransit, Supply to Maintenance, Shop Flow, and Serviceable Turn-In (discussed later) (5). In addition, Benson successfully tested the feasibility of using SPC in the base-level pipeline (4). A logical succession for continued follow on pipeline research would be to use SPC techniques to analyze the remaining segments.

Specific Management Problem

In 1989, the U.S. Secretary of Defense published the Defense Management Review Directive (DMRD) which set a target for reducing defense department expenditures at over $30 billion by 1995. Mandatory reductions in supply system costs are specifically addressed in DMRD 901 (1:53). Comprising an inventory of 2 million items and valued at over $25 billion, the USAF logistics pipeline is a substantial target for cutting supply system costs (11:34). A conceptual model of the USAF logistics pipeline developed four subsystems: acquisition, disposal, base-level, and depot-level (3:3). The depot-level subsystem of the USAF logistics pipeline is also known as the depot-level reparable pipeline. Experts estimate that a one-day average reduction in the depot-level reparable pipeline will produce inventory cost savings of approximately $50.9 million (23:14). Identifying improvements to the base processing segment of the depot-level reparable pipeline could be fundamental to meeting this inventory reduction.

Research Questions

Further research into process variations within the depot-level reparable pipeline's segments was recommended by Kettner and Wheatley in their recent AFIT thesis (13:217). This research will examine the Base Processing Segment to determine how variations in this segment of the depot-level reparable pipeline can be reduced by answering the following questions:

1. Do managers consider the effects of process variation in the Base Processing Segment of the depot-level reparable pipeline?
2. How can knowledge of process variation in the Base Processing Segment be used to manage the process?

Investigative Questions

Before the process variation in the Base Processing Segment can be measured, the process must be defined. Investigative question one establishes the boundaries (starting and stopping points for measurement) for the Base Processing Segment and defines the actions that occur within the process. The second investigative question will determine how the segment is currently being managed. Question three will be answered by conducting statistical process control charting of the flow of reparable items through the Base Processing Segment. Question four will be answered by introducing changes to the process and measuring the effect of the changes on segment flow times. The investigative questions for this study are as follows:

1. When do assets enter and what actions occur in the Base Processing Segment?

2. What data are collected and how is it used to make managerial decisions about retrograde asset flow?

3. Is the asset movement process within the Base Processing Segment under statistical control?

4. How should management use retrograde asset flow data to continually improve processes and ultimately reduce Base Processing Segment flow times?

Limitations

The scope of this study is limited to the Base Processing Segment of the depot-level reparable pipeline. Our research will utilize only F-16 reparable avionics asset flow time data. This was necessary because flowtime data for other assets was not available in sufficient detail to facilitate control charting. Due to time constraints, a long term working relationship with base-level pipeline managers was not possible. Therefore, continuous process improvement analysis will be conducted using a simulation model of the Base Processing Segment.

Chapter Summary

This chapter identified the need to further study the Air Force logistics pipeline, in light of decreasing DoD budgets. The logistics pipeline is comprised of four main subsystems: base pipeline subsystem, depot pipeline subsystem, acquisition subsystem and the disposal subsystem. The enhanced conceptual model of the depot-level reparable pipeline is divided into six major segments: Base Processing, Reparable Intransit, Supply to Maintenance, Shop Flow, Serviceable Turn-In, and Order and Ship Time.

Previous studies by Kettner and Wheatley, Benson and Hession, and by Benson investigated the effects of process variation on pipeline segment flow times (13; 5; 4). This thesis continues the study of the depot-level reparable pipeline by examining the effects of variation on the Base Processing Segment of the depot-level reparable pipeline to determine the effect of variation on that segment.

Thesis Overview

Chapter II presents an overview of current depot-level reparable pipeline studies and articles that pertain to pipeline research. In addition, literature focusing on process theory and statistical process control is discussed. Chapter III explains the methodologies emloyed and justifies the research design. Chapter IV contains data analysis and research findings. Finally, Chapter V provides conclusions, recommendations and suggestions for further research.

II. Literature Review

Overview

Chapter II examines current literature on the depot-level reparable pipeline, process management, process variation, and statistical process control.

Definition of a Logistics Pipeline

The logistics pipeline is an encompassing system through which "...material or personnel flow from sources of procurement to their point of use" (8:522). The definition used as the basis of research for AFIT logistics pipeline theses was developed by Bond and Ruth in 1989:

> This pipeline consists of an extensive network of interrelated systems whose collective efforts finance, procure, distribute, and maintain the weapons systems, facilities, spares, and consumable items used to achieve a high state of readiness and to support wartime objectives. (3:1)

Using Bond and Ruth's definition as the starting point for further research, a continuous succession of pipeline studies have dissected the logistics pipeline into smaller segments in order to identify its weaknesses and make steadfast improvements in its efficiency.

Previous AFIT Pipeline Studies

In 1988, HQ USAF, Assistant Deputy Chief of Staff, Logistics & Engineering, asked AFIT/LS to conduct thesis research on the pipeline. The initial request was for AFIT "...to collectively define the pipeline and piece together what information is now regularly collected and used by managers" (25:2). The goal of the research would ultimately be to reduce pipeline time; General Skipton recognized that reducing pipeline flow times would result in increased customer support with lower inventories.

General Skipton's request generated a series of theses on the Air Force Logistics Pipeline. The first of the theses was "A Conceptual Model of the Air Force Logistics Pipeline" by Bond and Ruth.

A Conceptual Model of the Air Force Logistics Pipeline. Working from their broad definition of the logistics pipeline and using the research question, "How do all of these components and subsystems fit together", Bond and Ruth developed a conceptual model (Figure 1) of the Air Force Logistics Pipeline (3:17). They identified four main subsystems that make up their conceptual model:

(1) The acquisition subsystem

(2) The depot pipeline subsystem

(3) The base pipeline subsystem

(4) The disposal subsystem

The authors not only found that processes within each pipeline subsystem were different from other subsystems, but they also discovered that each pipeline subsystem was

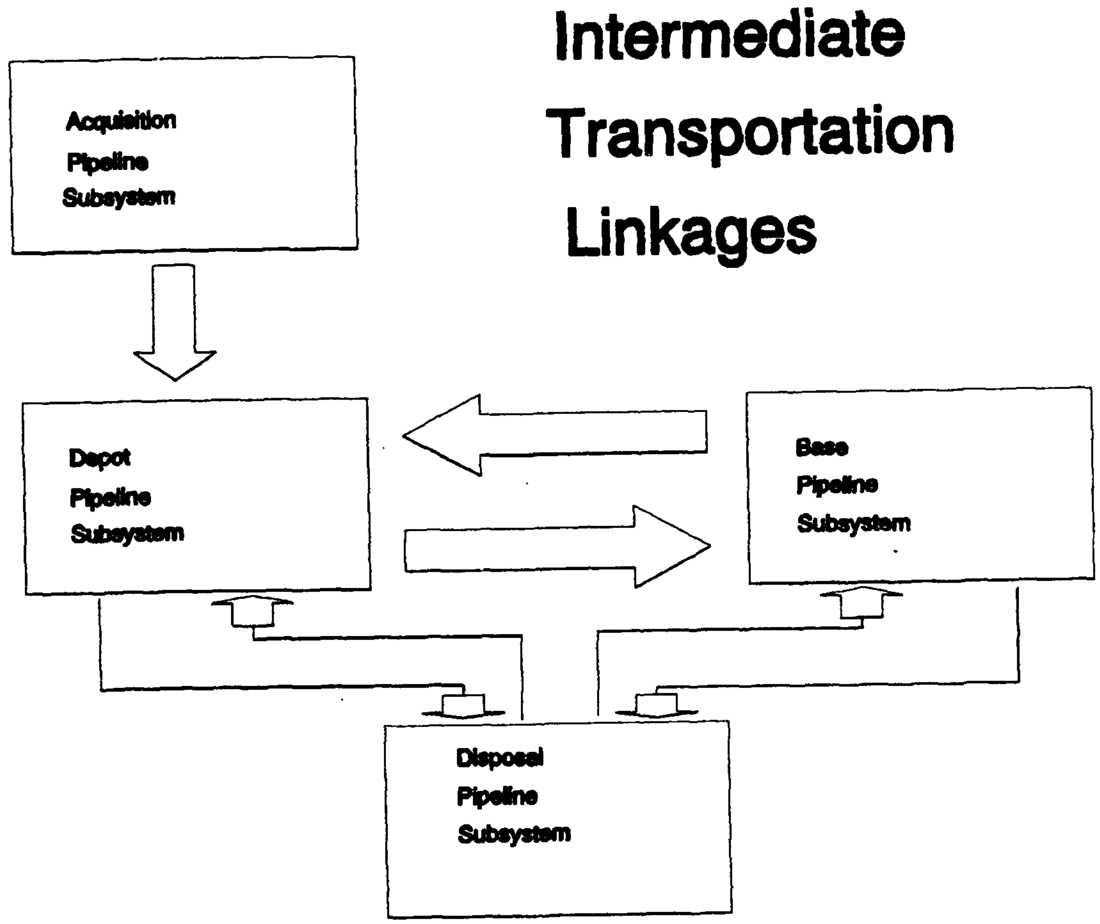


Figure 1. Conceptual Model of the Air Force Logistics Pipeline (3:169)

interrelated and dependent on other subsystems. The acquisition pipeline subsystem is responsible for the procurement and delivery of recoverable spares to Air Force depots. It is dependent on the depot-level pipeline subsystem for the determination of requirements to procure.

The depot-level pipeline subsystem incorporates the activities of supply, distribution, and maintenance divisions with a mission of managing the flow of reparable assets at the depots and between the depots and bases. The major activities accomplished in this subsystem include: spares requirements computation, workload planning, material requirements, scheduling, repair processes, and storage of reparable and serviceable spares.

The timely flow of serviceable reparable assets from the depot is the life's blood of the base processing subsystem. This subsystem is composed of base supply and base maintenance. Base supply orders, stores, and delivers the assets to the maintenance activity. Base maintenance installs the reparable assets and either repairs the broken asset or returns the broken asset to supply. If the asset is repaired, it is normally returned to the base supply's stock. When an asset cannot be repaired by maintenance, it is returned to the depot for repair or disposal.

The disposal pipeline subsystem manages all items turned in as excess or condemned. The property is made available to other DoD users or auctioned to the public (3:162-166).

Bond and Ruth's conceptual model is significant because it represents the platform from which other, more in depth, studies of the pipeline were launched.

Recognizing the importance of their research, they called it "...an initial step in pipeline studies", and suggested that future pipeline models provide even greater depth in describing each subsystem (3:xii, 212).

<u>A Conceptual Model of the Depot Level Reparable Pipeline</u>. Kettner and Wheatley furthered pipeline research with their 1991 Thesis, "A Conceptual Model and Analysis of the Air Force Depot Supply and Maintenance Pipeline for Reparable Assets". The focus of their study was on the depot-level reparable pipeline. The authors successfully expanded the depot pipeline subsystem of the logistics pipeline developed by Bond and Ruth by addressing the following research question:

> What is the flow of reparable assets and associated information through the depot-level maintenance and supply systems, and what is the impact of these systems on the availability of reparables within the logistics pipeline? (13:15)

The following investigative questions were used:

> 1. What depot-level reparable pipeline models exist and are they valid?

2. What enhancements can be made to current models to better reflect the actual depot supply and maintenance reparable pipeline processes?

3. What data are being collected on the reparable pipeline and what information is being used to manage the flow of assets through the pipeline?

4. What statistical distributions describe the duration of processing in the depot-level reparable pipeline? (13:16-17)

By examining Kettner and Wheatley's investigative questions, it becomes apparent that they were going to study the pipeline as an interrelated system. And by doing so, Kettner and Wheatley were able to give researchers a roadmap to a very complex system.

Starting with Bond and Ruth's depot pipeline subsystem, Kettner and Wheatley expanded the subsystem (Figure 2) into six segments: Base Processing, Reparable Intransit, Supply to Maintenance, Shop Flow, Serviceable Turn-In, and Order and Ship Time (13:119-127). A reparable asset enters the depot-level reparable pipeline when the base-level maintenance shop identifies the asset as not-reparable-this-station (NRTS). When the NRTS decision is made by the base-level maintenance shop, the Base Processing Segment (Figure 3) of the depot-level reparable pipeline begins (13:127). In the Base Processing Segment, unserviceable parts are received in base supply from the maintenance shops and are inspected by supply personnel. When the inspection is

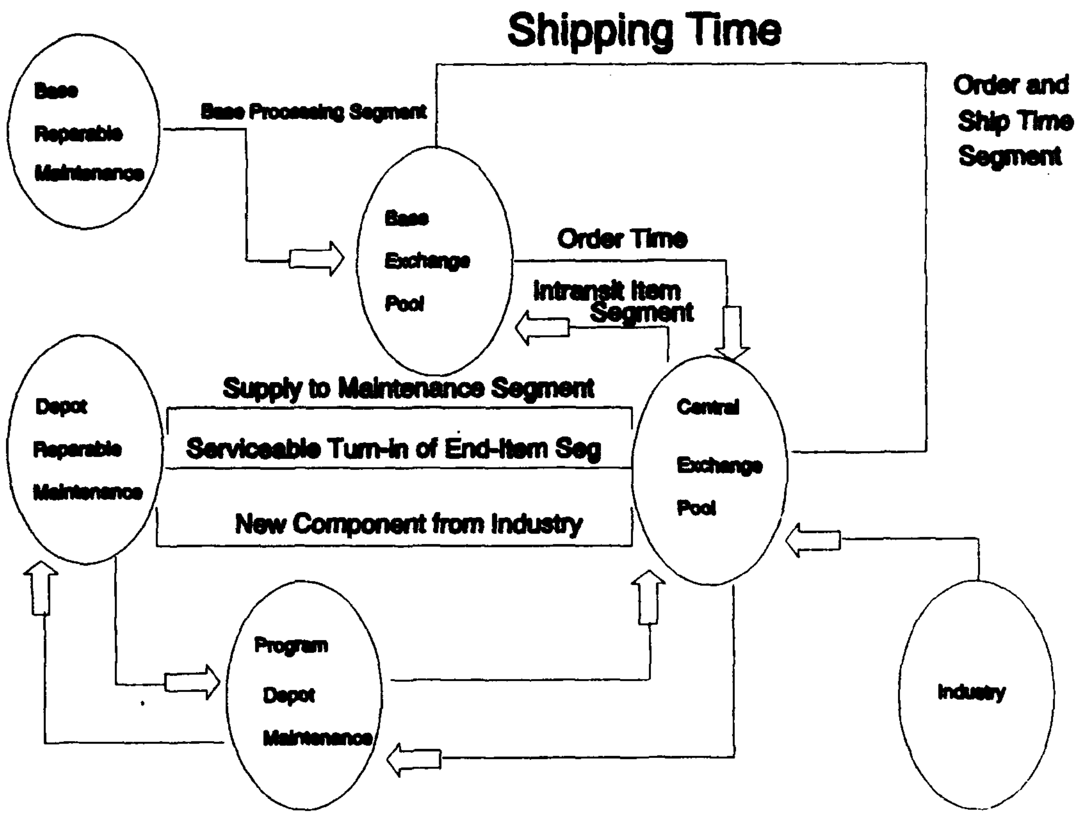


Figure 2. Enhanced Depot-Level Reparable Pipeline Model (13:117)

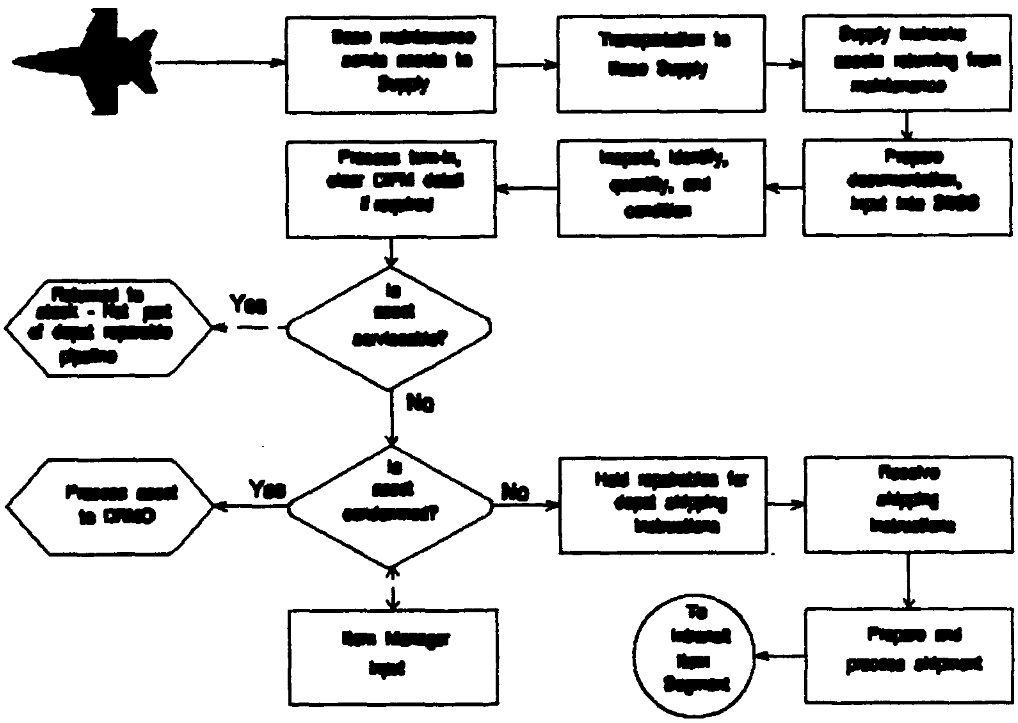


Figure 3. Base Processing Segment (13:128)

completed and all data is verified, the supply accountable records are updated. This update transfers item accountability from maintenance to supply. The reparable items are now awaiting shipping instructions from the item manager at the responsible depot. "Once these instructions are received, a shipping document is prepared and the asset [is] removed from its warehouse location and sent to the packing and crating section of the base transportation office" (13:129). Movement of the asset from supply to transportation signals a change to the Intransit Segment of the depot-level reparable pipeline.

The Intransit Segment starts when transportation receives the asset from supply. When transportation receives the asset, "...the supply documents are verified to ensure they are filled out correctly and are attached to the right parts" (13:130). The assets are crated for shipment to the appropriate depot for repair, and the shipping labels are affixed to containers. Once the property is prepared for shipment, arrangements are made with carriers based on the shipping priority of the item. Finally, the items are transported to the depot. When the assets arrive at the depot and the paperwork is transferred, the Intransit Segment stops and the Supply to Maintenance Segment begins (13:130-133).

Assets arriving at the depot are processed into the depot computer systems and held by depot supply awaiting maintenance. The assets remain in the supply warehouses until maintenance is capable of performing the repairs. When the asset is requested by a maintenance shop, the asset is removed from the warehouse and issued to the maintenance repair shop. Accountability of the asset transfers to maintenance when the issue document is signed. This action also represents the start of the Shop Flow Segment of the depot-level reparable pipeline (13:135-139).

Kettner and Wheatley identified the Shop Flow Segment of the depot level reparable pipeline as the "most complex segment of the pipeline" (13:139). When parts arrive at the Maintenance Inventory Center (MIC), accountable records are updated in the supply computer system, work control documents are printed, and shop schedulers are notified. The assets are temporarily stored in the MIC until a repair shop requests the asset. Once delivered to a repair shop, an asset will be tested, then repaired or condemned. After the repairs are completed and the assets test serviceable, the Shop Flow Segment of the pipeline is complete (13:139-147).

"The Serviceable Turn-In Segment of the depot-level reparable pipeline begins after repair has been completed on the assets by the depot maintenance shop" (13:147). The MIC notifies the item manager that the item is repaired through an update to the D035 system. The items are returned to the

Depot Supply Central Receiving Section for disposition. If a requisition is outstanding from a using base, the item is shipped. All other repaired assets are returned to depot stock. This segment ends when central receiving processes the repaired assets (13:150).

The Order and Ship Time segment of the depot-level reparable pipeline begins when an order is placed from a base to the depot and ends when the asset is received at the base. This segment is comprised of three elements: order time, processing time, and shipping time. The order time begins when the base-level SBSS computer system processes a requisition and ends when the requisition is received at depot. Processing time begins when the requisition is received at depot and stops when the property is handed over to a carrier for shipment. "Shipping time begins when the carrier receives an asset and ends when the asset is delivered to the requesting base" (13:150-154).

In addition to modeling the pipeline, Kettner and Wheatley conducted an analysis on the information being used to manage the flow of assets through the pipeline (13:166). They found that "[t]he current pipeline control standards are means. Little or no consideration is given to their associated variance" (13:211). This finding is important because it shows that the pipeline is not being managed as a process, but rather as a set of independent events. Through statistical analysis, Kettner and Wheatley found significant variance in each segment of the depot-level pipeline and recommended future research "focus on the development of adequate pipeline control standards" (13:217).

Planning and Enhancing the Depot-Level Processing of Exchangeable Assets with a Vision Toward the Future. Benson and Hession sought to "...examine methods for reducing the process variation of the reparable asset flow through the depot-level reparable pipeline and to lay a foundation for continuous process improvement" (5:195). Their thesis focused on three segments (modeled by Kettner and Wheatley) of the depot-level reparable pipeline: Reparable Intransit Segment, Shop Flow, and Serviceable Turn-In Segment. Their research was the first full scale effort devoted to examining the performance of processes within the depot-level reparable pipeline.

Benson and Hession studied four interrelated properties of the depot-level reparable pipeline processes: flow of assets, data collection, process status, and data evaluation. The authors considered these four properties "...important to the effective and efficient operation and management of processes within the depot-level reparable pipeline" (5:196).

To illustrate the first property, flow of assets through the depot-level reparable pipeline, Kettner and Wheatley's Enhanced Depot-Level Reparable Pipeline Model was selected. Benson and Hession concluded that Kettner and Wheatley's "...detailed depiction of pipeline processes and actions provided an accurate account of the maintenance, transportation, and distribution processes that occur within the depot-level reparable pipeline" (5:197).

Armed with a model of the processes, the authors proceeded to the data collection phase of their study. For the Reparable Intransit, Supply to Maintenance, and Serviceable Turn-In Segments, D035K, Wholesale and Retail Receiving/Shipping System, historical data were used to compute flow times. A manual data collection system was established in the Shop Flow Segment to collect flow time data (5:94). Benson and Hession made two important findings regarding data collection. First, the D035K system does not compute mean flow times or flow time variation. Second, there is no automated system to collect shop flow time data. These findings are particularly important because of flow time data essentiality for effective process management (discussed later). Benson and Hession determined process status through constructing and analyzing statistical process control (SPC) charts (5:198). Working from the premise that continuous process improvement requires the identification and elimination of special causes of variation, control charts were constructed for each segment of the depot-level reparable pipeline under study. "In the construction of the final 14 control charts..., 10 of the 14 processes were determined to be in statistical control" (5:198). Unfortunately, these processes were in control by accident as there were no efforts in place by management to identify or reduce process variation.

For their final factor, data evaluation, Benson and Hession wanted to examine "[w]hat efforts are underway to reduce the length of reparable asset flow times..." (5:92). They discovered the only data being used to manage the pipeline is actual mean flow times from the D041 system. The D041 system uses the data to compute buy and repair requirements for reparable assets (5:199). In their analysis of flow times, the observed mean differed from the D041 standards in every instance (5:192). The authors summarized their data evaluation as follows:

> ...data collection for reparable asset flow times and management information systems needs to be improved. The inability of current systems to compute accurate flow standards and measure process variation severely inhibits efforts to reduce the depot level reparable pipeline. (5:201)

<u>A Conceptual Model and Analysis of the Air Force Base-Level Logistics Pipeline for Reparable Assets</u>. The objective of this thesis was to "provide a descriptive study

of the base-level segment of the logistics pipeline" (9:119). To accomplish this, the research focused on three components:

> 1. [A]n extensive review of literature pertaining to the base-level subsystem of the logistics pipeline.
>
> 2. [I]nterviews with base-level military and civilian logistics managers and technical personnel from selected bases.
>
> 3. [A]nalysis of data gathered on a selection of reparable assets at Grissom AFB (SAC), Indiana, home of the 305th Air Refueling Wing, and Langley AFB (TAC), Virginia, home of the 1st Tactical Fighter Wing, and from the literature. (9:11)

The authors worked from the premise that for "Air Force managers to properly evaluate the base processing segment of the pipeline, it is crucial to define each element of the process and then analyze how the elements interact" (9:77).

Drawing from the base processes in both the Bond and Ruth model and the Kettner and Wheatley model, the authors constructed conceptual models focusing on minute procedural detail. However, it was soon discovered that the required data necessary to track the flow of reparable assets through their conceptual model was not available from existing base-level computer systems (9:119). The authors were unsuccessful in their attempt to evaluate the base-level process through the use of mean flow times.

Process Management

To better understand pipeline processes, what causes variation in process output, and how to manage the system of processes, it is necessary to investigate specific fundamental systems concepts. According to Melan, the General Systems Theory creates a foundation that can be applied to productive systems (17:367). Consider an enterprise such as a logistics pipeline, an open system that interacts with and is supported by its environment. The system uses a conversion to transform external environmental inputs into outputs. Thus, the principal element of this theory is a transformation. Within the system, each activity or subsystem may be viewed as interacting components that accepts inputs and converts these inputs into outputs. Each output then becomes the input for the next interacting component (17:397). The generally accepted definition for a process is "...a series of actions or operations that transform inputs into outputs. A process produces output over time" (10:710). The principal element, transformation, is the common factor that links the General Systems Theory with the process definition.

Figure 4 presents a model of a basic process. Over time, inputs from a supplier are transformed into outputs for a customer. There are five generic resources that make up both inputs and outputs: People, Method, Material, Equipment, and Environment. Managers should not focus on

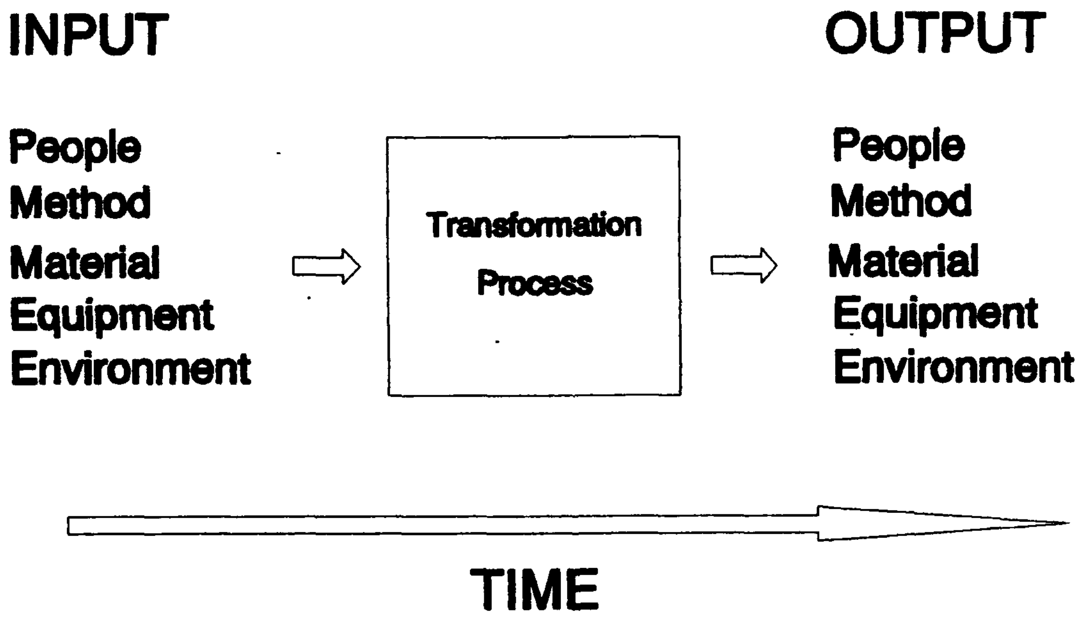


Figure 4. Basic Process

the material resource input or output alone, because over a period of time, all the resources will change their state (26:7-8).

In the Air Force, work flows between sections, flights, squadrons, or groups, and organizational ownership of the work change. Because work takes place at an operational level, organizational conflict can suboptimize the working processes. Process management can be utilized to emphasize the meeting of work flow requirements. "Process management is the monitoring, controlling and improving of components and/or subsystems of a transformation process for the purpose of improving the quality of the output of the process" (10:715). To successfully conduct process management, Melan proposed that managers take the following six steps:

1. Establish Ownership of the Process.
2. Establish Work Flow Boundaries.
3. Define the Process.
4. Establish Control Points.
5. Implement Measures.
6. Take Corrective Action (17:398-401).

Appropriate data collection both inside and outside the process is vital when applying process management techniques. Managers can improve quality, productivity, and effectiveness by viewing each operation as a process and utilizing the concepts of process management.

Understanding the Pipeline Process. Reparable assets flow continuously through each segment of the depot-level reparable pipeline. As the assets and information about these assets flow through the pipeline, the output from one segment becomes the input for the succeeding segment. A transformation in some form takes place within each segment, whether the transformation be an update to accountable records, asset storage, movement, or a repair activity. Despite the similarities described above with those of our process definition, many people who work with the pipeline fail to view it as a process. This failure to recognize processes occurs throughout business and industry and frustrates those people who are interested in improving quality. Many people regard processes as only occurring in manufacturing settings. However, experts agree that processes apply to manufacturing, services, and their management alike (26:5-6). Certainly, a large portion of the depot-level reparable pipeline can be viewed as service and management intensive. Pipeline technicians and managers must become aware that these nonmanufacturing activities should be viewed as processes to facilitate lasting improvements.

Within the Base Processing Segment of the depot-level reparable pipeline, an aircraft maintenance technician declares an asset not-reparable-this-station and thus begins the supply of input to our chain of processes. The Base Processing Segment of the pipeline (Figure 5) is comprised of the subsegments Maintenance-To-Supply, Supply Processing, and Supply-To-Transportation, all of which depend on each other for input and output. Communication also takes place between each subprocess and will be discussed later. For now, it is important to realize that one process's input is another process's output. Each subsequent activity in the chain is influenced, controlled, or dominated by an input, output, or both. This is known as a dependent relationship (26:94). Once the dependent nature of these relationships is realized, managers can consider how fluctuations or changes in any of the subprocesses might effect the other activities in the chain. With the understanding now gained of the pipeline process and the dependent relationship that exists within, an examination of process communication is now possible.

Process Communication. As shown by the process model in Figure 6, the customer-supplier relationship is assisted by two communication sources. The voices come from the customer and from the process itself. Scherkenbach calls these "the Voice of the Customer and the Voice of the Process (26:12). The Voice of the Customer (VOC) includes feedback from all those customers and potential customers

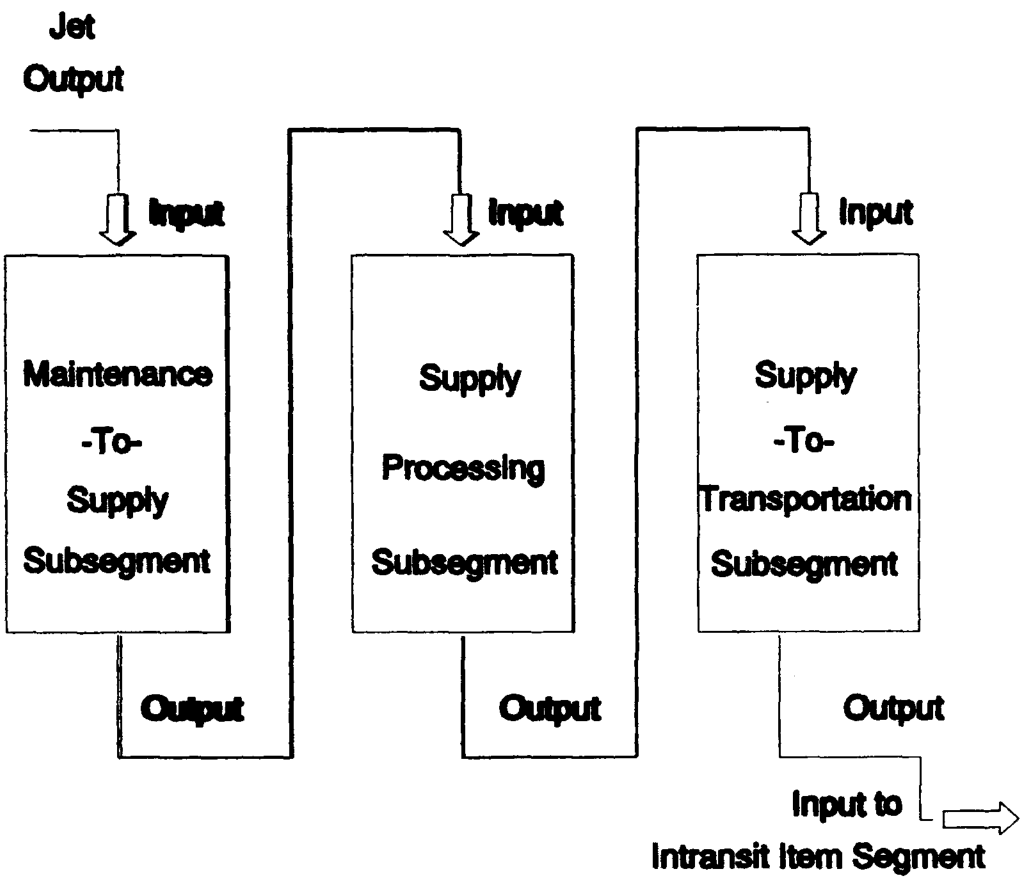


Figure 5. Base Processing Segment Chain of Processes

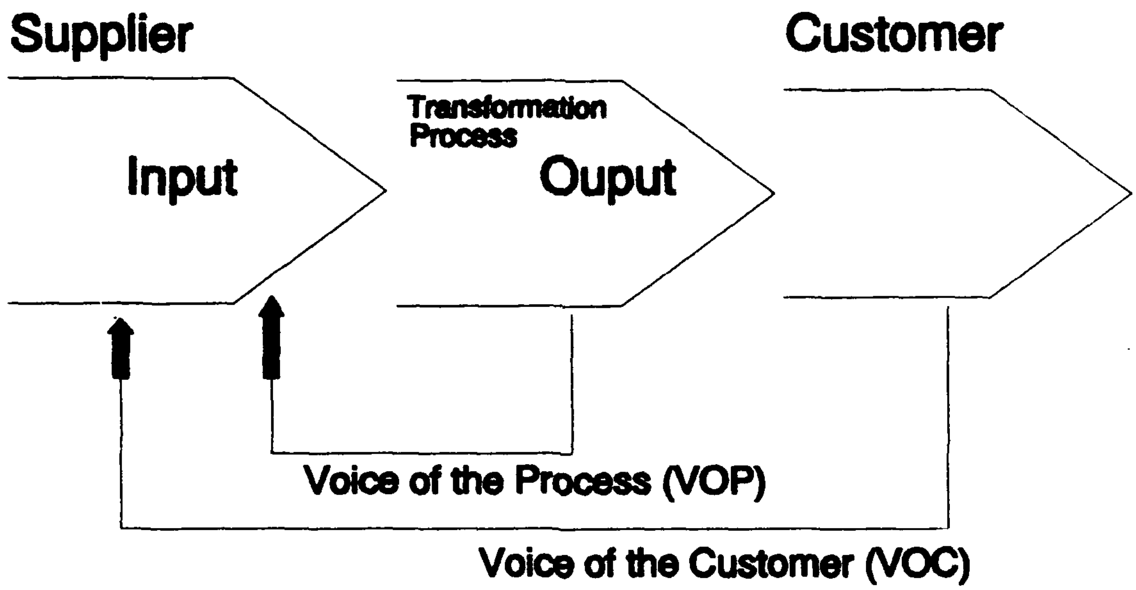


Figure 6. Customer-Supplier Process Model
With Feedback (26:11)

who can be impacted by what you provide as the supplier. The feedback may be viewed as a prediction, time window, target, or tolerance specifications. The VOC may be influenced by such things as candid discussions with your customers, the interaction of multiple customers, or critical analysis.

The Voice of the Process (VOP) is the actual output of the process, and what it communicates will rely heavily on the sampling method used to take readings. The VOP is influenced by adjustment of People, Material, Method, Equipment, and Environment. Every process manager should try to match the VOC and the VOP (26:12-14).

In our imperfect world, the VOC and VOP rarely match. This variation should not surprise anyone. Not all customers have the exact same expectations. However, if variation among customers is predictable over time, it may be possible to view the variation as a distribution which provides insight to collective customer desires (26:19-20).

Variability in the process surfaces directly from the process output. Some examples could be the variation in lengths of metal pipe coming out of a cutting machine or the various lengths of time it takes to accomplish a repetitive clerical duty. Like VOC distributions, these VOP ranges can display various shapes, central tendencies, and spreads (26:21).

In our Base Processing Segment of the depot-level reparable pipeline, micro-communication takes place as inputs and outputs to our subprocesses. When one considers the size and complexity of the whole logistics pipeline, it becomes increasingly difficult to comprehend the enormous number of micro and macro communications representing a profusion of dependent events. In addition, there are external voices that will normally present themselves as noise (Figure 7). The external voice may come from Congress intervening in the form of financial support, changing national economic conditions such as inflation, or a natural disaster destroying a portion of a repair facility. Process managers at each respective level in the system hierarchy must filter the noise to the best of their abilities and listen closely to the VOC and VOP. There should also be an overall system manager to merge the various voices into a singular voice of system expectations. Silver recognized this missing director during his research and stated, "What was lacking, however, was a systematic approach to decision and policy making for the total pipeline which crosses the various boundaries of the various segments" (27:33-34).

Before beginning the process to control variation, one must determine a measure that accurately reflects the VOP. A logical measure in the pipeline arena is asset movement times within each identified segment. The movement times are valid because they affect mission readiness, financial

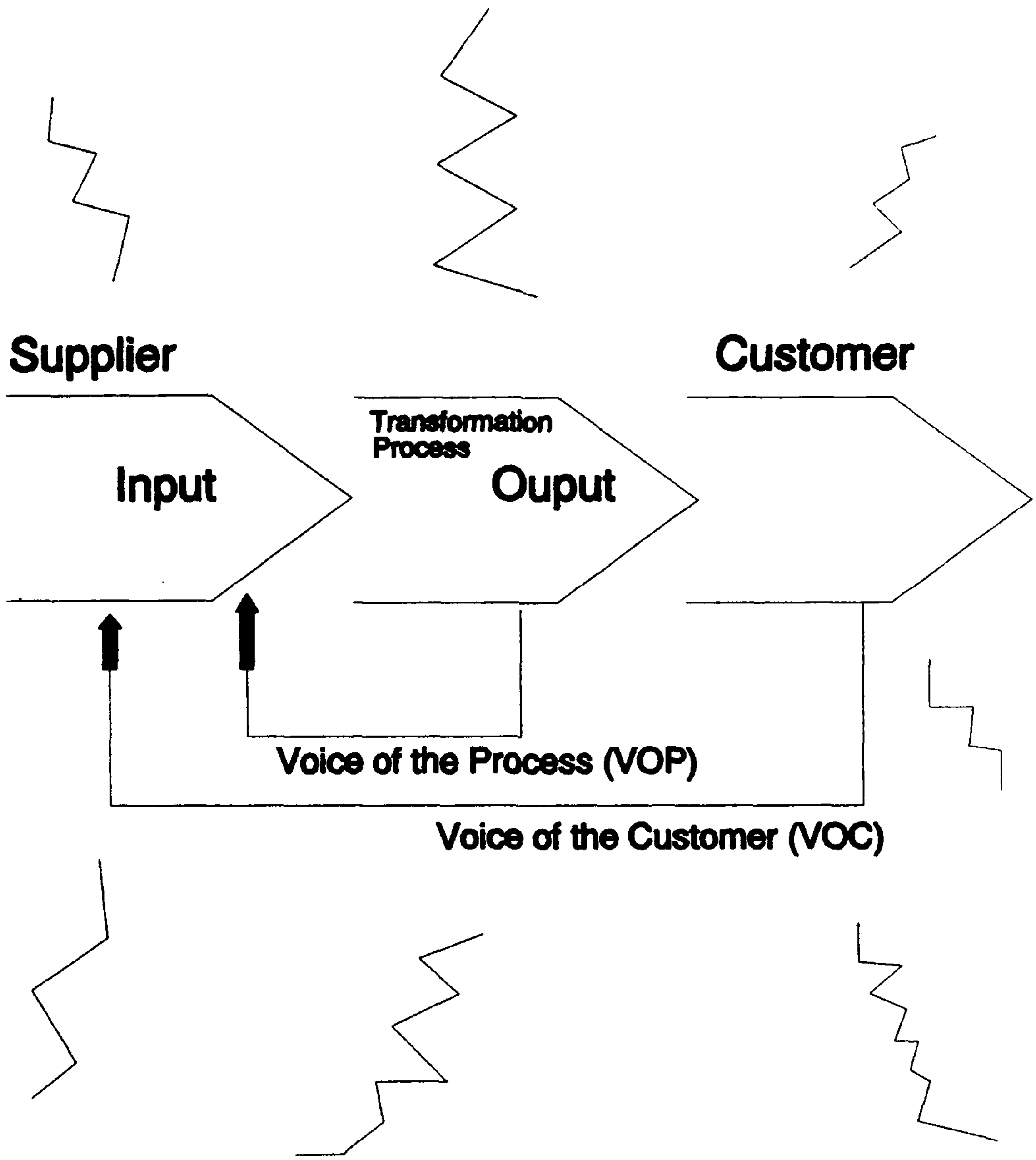


Figure 7. Many VOCs and VOPs With Noise

considerations, and asset availability (5:72). The tools necessary to take-on such an approach are available and the feedback delivered by the VOC and VOP provides the signals necessary to begin an understanding of variation.

Process Variation

What is variation? The concept in its simplest form is easy to understand. Variation is the measurable change of an attribute or characteristic that differs between like items or like activities. How variation relates to process is paramount to this study. The key point about a process and its output follows: "No two items produced by a process are the same. Variability is an inherent characteristic of the output of all processes" (10: 711). Likewise, Wheeler and Chambers begin their text on statistical process control with: "One axiom has been apparent from the beginning of man's effort to make things. No two things are alike" (29:1). Since the concept of variation is relatively simple and understandable, the difficulty must lie in getting people to recognize variability and make use of it.

> Because variability is not commonly recognized in our formal processes, there is a lack of "usable" methods to "efficiently" manage it. I stress the word usable because if the methods are too overly complex or obtuse, they will not be used. (26:21)

Once variability is recognized, process managers must next comprehend the two major types of variation and how each should be handled.

Types of Variation. In the early 1920s Dr. Walter Shewhart of the Bell Telephone Laboratories studied process data. He first made the distinction between controlled and uncontrolled variation. "Controlled Variation is characterized by a stable and consistent pattern of variation over time. Dr. Shewhart attributed such variation to 'Chance' Causes" (29:4). The distinction becomes obvious when one learns that "Uncontrolled Variation is characterized by a pattern of variation that changes over time. Dr. Shewhart attributed these changes in the pattern of variation to 'Assignable' Causes" (29:4). Process factors such as People, Material, Equipment, and Environment all interact to create variation. This random type variation is fairly consistent over time because it results from many sources. The resulting variation is thought of as controlled variation. At other times, special factors can convey significant influences on measured variation. Examples might include a machine running outside of recommended specifications, unplanned changes in raw materials, or simply untrained employees who are trying their best. The impact of such identified and assigned causes would create dramatic changes in variation patterns, otherwise known as uncontrolled variation (29:4-5).

Approaches to Variation. There are two ways to improve processes: change the process or take action on Assignable Causes of variation. A stable, consistent process displays only controlled variation. The output of such a process includes only that variation intrinsic to the process itself. In other words, the variation is due to common causes and is attributable to the design of the process. The process itself must be changed to improve or reduce controlled variation. Uncontrolled variation is displayed in processes that change from time to time. The process is deemed both inconsistent and unstable. This second form of variation comes from instability, not from the way in which the process was designed to operate. To correct or improve a process that displays uncontrolled variation, the Assignable Cause must be removed if detrimental; if benefit can be derived, the Assignable Cause should be incorporated into the process if possible (29:6-7).

A fundamental goal of process management is to identify uncontrolled variation. The tool to accomplish this is Shewhart's control chart, first published in 1924. Shewhart's methods did not receive acclaim because most manufacturers regarded them as too technical for their employees and failed to see the usefulness to management. Dr. W. Edwards Deming worked with Shewhart and recognized the power of control charting. He renamed what Shewhart identified as controlled and uncontrolled variation to later be known as common and special cause variation. Also, Deming focused his attention not on the source of variation but on who was responsible for doing something about it (29:7-8). Deming developed a management philosophy of continuous quality improvement that compliments and supports statistical methodologies. Together, the methods and management combine to form a powerful team for reducing variation.

> There is empirical evidence that control charts effectively direct attention toward special causes of variation when they appear and reflect the extent of common cause variation that must be reduced by the action of management. (26:189)

Remembering the definition of a process and applying the methods of Shewhart, our charge for identifying variation requires a new definition. "The process of monitoring and eliminating variation in order to keep a process in a state of statistical control or bring a process into statistical control is called Statistical Process Control (SPC)" (15:725). SPC is the topic for our next area of investigation.

Statistical Process Control

According to Wheeler, "Statistical Process Control (SPC) is a way of thinking with some techniques attached" (29:21). This revolutionary way of thinking is helping U.S. business, industry, and government increase standards of quality. SPC can lead to setting management practices in place which make it possible to manufacture a product or provide a service and do every job right the first time. This control technique eliminates waste and rework. Because it often must reverse long-established mindsets and procedures and triggers a major cultural change, organization-wide SPC usually takes years to develop. The cultural change must begin with top management and cascade down through the depths of an organization. To start, an organization's operational goal must be directed toward continuous improvement rather than toward conformance to specification. Once continuous improvement is chosen, an organization can employ these primary tools to facilitate SPC: a process flow diagram, cause-and-effect diagram, control charts, and histograms.

Process flow diagrams are so simple that they are frequently overlooked. The activity that requires improvement is depicted in diagram form, with decisions about prioritization and other mental procedures incorporated into the physical flow. The examination of current procedures and management directives assists workers in relating the activities to a complete process. Brainstorming by workers who are completely familiar with the operation is an appropriate method. By learning what the actual process is, and not what we may think it is, immediate improvements can often be made (7:44).

Cause-and-effect diagrams are useful for identifying relationships that exist within or those impacting from outside the target process (Figure 8). They are designed to show a graphic representation of the relationship between problems and their sources (29:312). Decisions can then be made regarding what data needs to be collected. Cause-and-effect diagrams serve to provide both likely and unlikely reasons for delays, errors, or other circumstances impacting

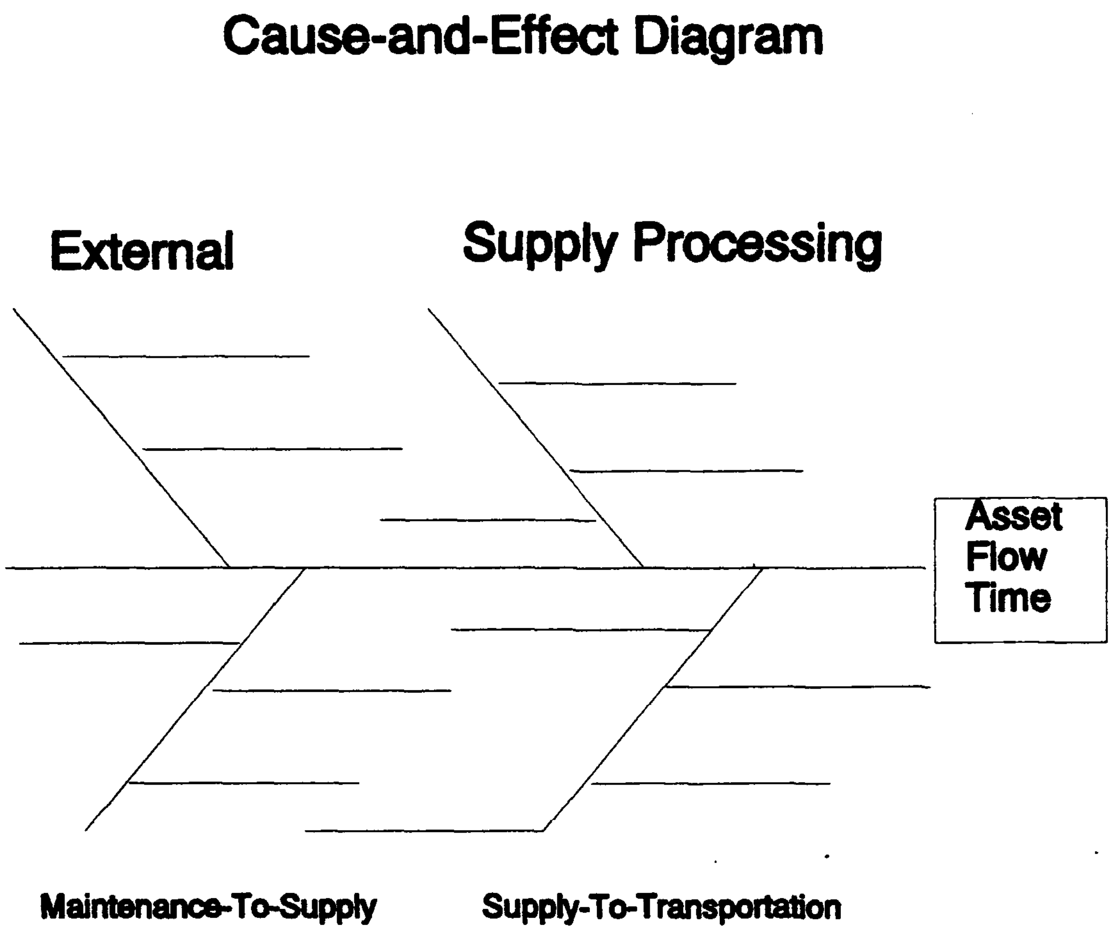


Figure 8. Sample Cause-and-Effect Diagram

the process. Effort can then be pinpointed toward the most likely causes of undesirable effects and the needed data collected (7:45).

A control chart is a graphical representation of the variability in a process (Figure 9). Control charts are useful for evaluating the past performance of a process and for continuing to monitor performance. The chart centerline represents the average characteristic of interest from the process. The top line is the upper allowable variation, called UCL for Upper Control Limit, and the lower line is the minimum or LCL for Lower Control Limit. Each of the UCL and the LCL is established at plus or minus three standard deviations (3 sigma) from the centerline. Samples of parts or processes are checked over a predetermined time. Sample data are entered in the chart with an X. The extent of variation can be easily calculated and plotted for subgroups, using an X-bar chart. In practice, the X-bar chart is usually developed with an R-chart (Figure 10). An R-chart is similar to the X-bar chart except that the range of variation or distance from the centerline is noted (22:627). The same figures can be used with a vertical line to show how nearly identical units become clustered. This chart is called a histogram (Figure 11).

Control charts for high speed, complex processes can be kept by computer, while slower, more routine processes allow for actual production workers or service providers to keep the data by hand. Being involved in both the process itself

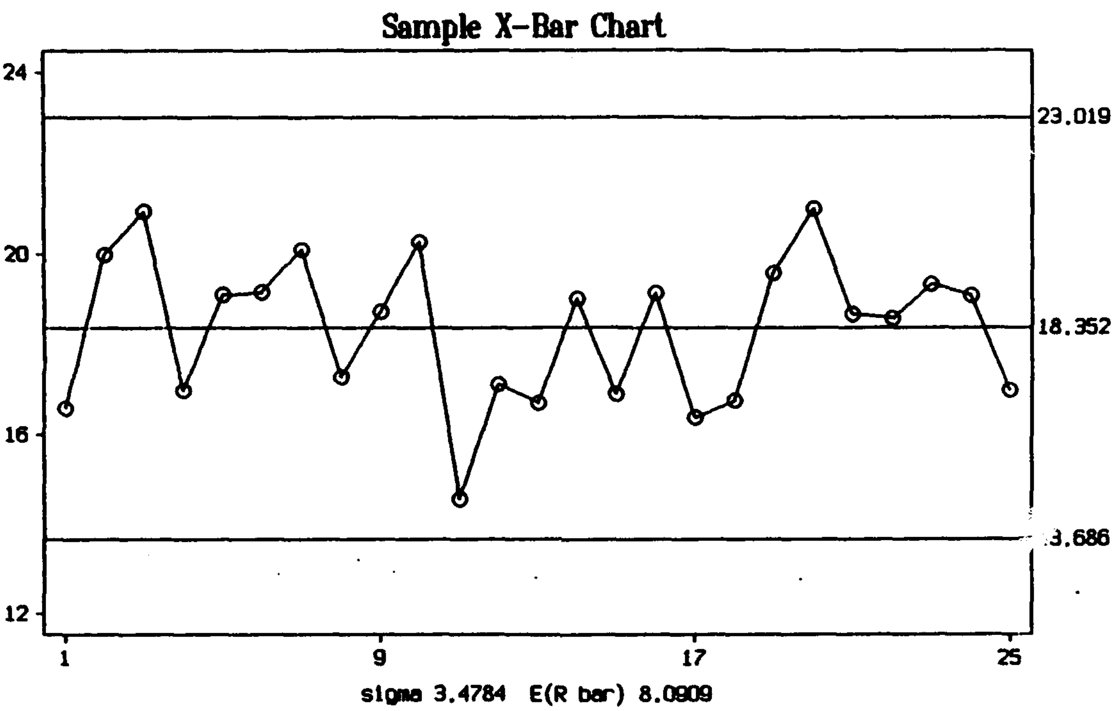


Figure 9. Sample Control Chart

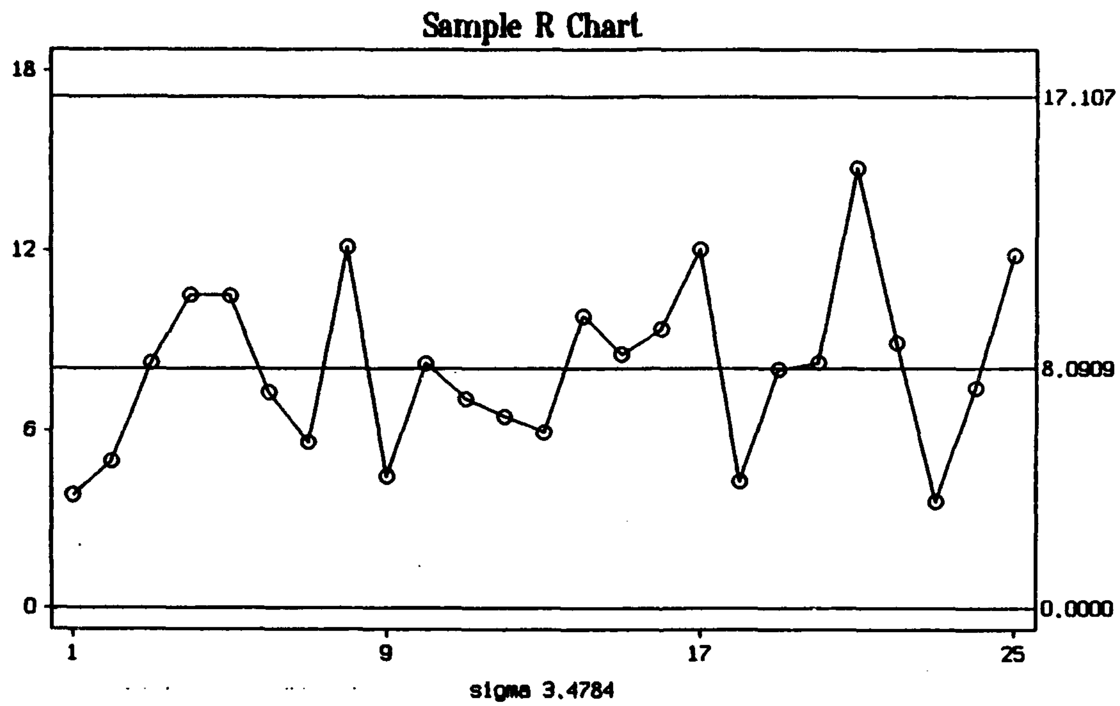


Figure 10. Sample R Chart

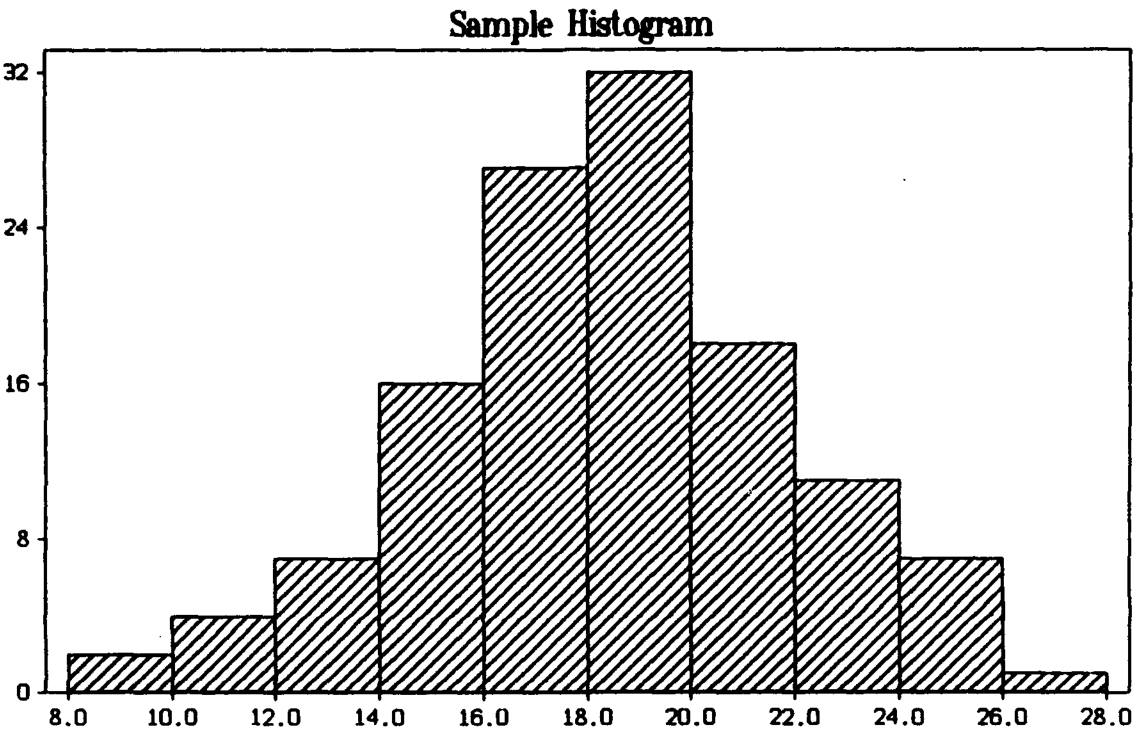


Figure 11. Sample Histogram

and data collection gives employees a personal feeling and more closely relates the chart to the work. The activities associated with the Base Processing Segment of the depot-level reparable pipeline are simple and routine. Therefore, data collection can be accomplished by hand. Using simple math calculations, hand-held calculators, or basic spreadsheet computer software, employees involved in reparable item processing can easily monitor the process.

Process Capability. Can the processes associated with base-level retrograde item movement meet specifications? To arrive at a solution to this question, the processes must display a reasonable degree of statistical control. According to Wheeler, "...the capability of a process depends upon both the conformity of the product and the stability of the process" (29:117). His reference to the conforming product can also be applied to services, such as the services provided by personnel employed in the reparable asset processing. Therefore, the capability of a process depends upon both the conformity of the service and the stability of the process. A stable process will possess a well-defined capability and, within limits, will allow the prediction of future performance.

Plotting individual values taken directly from a control chart to a histogram is a simple and effective method for assessing the stability of a process. The axis of the histogram can show the specification limits or management objectives. By relating the histogram to these limits or objectives, the capability of a stable process can be exhibited.

Natural process limits can also be used to define the actual capability of stable processes. The calculation of natural process limits is as follows:

$$\bar{\bar{X}} +/- 3 \text{ Sigma}(X) = \bar{\bar{X}} +/- 3 \bar{R}/d_2 \quad (29:119)$$

Natural process limits are what Scherkenbach described as the Voice of the Process (VOP). Process capability measures then can ascribe natural process limits or the VOP, to the process specifications or management objectives. These management objectives are know also by another term Scherkenbach uses, the Voice of the Customer. Additional discussion of process states and how knowledge of these states can be used by managers to work toward continuous improvement will be presented in Chapter 3.

Chapter Summary

This chapter began by defining a logistics pipeline, an extensive network of interrelated systems working together to achieve specific logistical objectives. Two conceptual pipeline models were then reviewed. In the Bond and Ruth model, broad overviews of the USAF logistics pipeline processes and interrelated activities were developed. In the second model, Kettner and Wheatley focused on the depot-level reparable pipeline (DLRP). They identified the six segments: Base Processing, Reparable Intransit, Supply to

Maintenance, Shop Flow, Serviceable Turn-In, and Order and Ship Time. This model also produced detailed explanations of the internal activities within each segment, helping one to understand how reparable assets flow through the system.

Following the discussion of conceptual models, two additional academic studies where highlighted which attempted to measure the performance of specific DLRP segments. Research conducted by Benson and Hession was the first full-scale effort to measure process performance within the DLRP. They found that current management information systems were not capable of providing reparable asset flow time data and inhibited efforts to reduce the DLRP. In the other research project, a detailed description of the Base Processing Segment of the DLRP was produced. However, the authors were unsuccessful at evaluating base-level processes through the use of mean flow times.

This chapter concluded by summarizing current literature in the areas of processes management, process variation, statistical process control, and process capability. These subjects were developed by relating their key concepts to aspects and characteristics of the base processing segment of the DLRP, thus establishing a foundation for the rest of our research.

III. Methodology

Overview

This chapter outlines the methods used to determine the effect of flow time variation on the performance of the Base Processing Segment. Wheeler's approach to continual process improvement served as our road map (29).

Our study is separated into two parts: (1) a one-factor experiment which analyzes the response of the process to different levels of a cause variable and (2) an analysis of the Base Processing Segment at Moody AFB, Georgia. The one-factor experiment illustrates the four states of Wheeler's paradigm and clearly demonstrates how different levels of variation affect the process. In the one-factor experiment, control charts are used in the active mode. In the active mode, "...changes in the process (the cause variables) are made, and then the effect of these changes on the response variable [flow time] being plotted on the control chart is observed" (18:81-82). Details of the experimental design are discussed later in this chapter. The second part of the study assesses the state of the Base Processing Segment at Moody AFB, Georgia. This assessment demonstrates the use of control charts in the passive mode. "When a control chart is used in the passive mode, action begins after the effect (i.e. a special cause) has occurred" (18:81). In this part of the study, we did not change the process. Therefore, control charts remain passive.

Continual process improvement hinges on management's ability to identify and remove causes of variation. Recall that two types of variation exist which impact any process: Controlled and Uncontrolled. Controlled variation, characterized by a pattern that is stable and constant over time, is attributed to Chance Causes. Uncontrolled variation patterns change over time and these changes can be attributed to Assignable Causes (29:4). The tool found useful for identifying variation and gaining knowledge of the process is the control chart.

Since our goal was to determine how knowledge of process variation in the Base Processing Segment can be used to reduce flow times in the depot-level reparable pipeline, *control charting* was used *extensively* in our analysis. "Use of a control chart to study a process to bring it into a state of statistical control is an analytic study" (18:54). The focus of an analytic study is on the cause-and-effect system (18:54).

Before we detail the one-factor experiment and outline the Moody AFB process analysis, it is necessary to describe: our method for sample selection, the Base Processing Segment, Wheeler's paradigm, and the procedures for using SPC. Once these fundamental concepts are presented, it then becomes possible to describe the one-factor experiment used to demonstrate Wheeler's paradigm. Finally, we outline the methodology used to assess the capability of the Base Processing Segment at Moody AFB, Georgia.

Sample Selection

To adequately analyze the effects of variation in the Base Processing Segment, we needed a data base in sufficient detail to allow control charting. The data collection system currently contained in the SBSS (discussed later) does not collect flow time data for each subsegment of the process. Therefore, we utilized reparable asset flow time data collected under the CORONET DEUCE II program. Units participating in CORONET DEUCE II established data collection points to track F-16 avionics reparable assets flowing through each workcenter (14; 24). From this data we were able to compute the flow times between subsegments.

Use of the CORONET DEUCE II data restricted our analysis to F-16 reparable assets and to the ten bases participating in the program. We eliminated three Air National Guard bases (Buckley, Richmond, and Sioux Falls) because of their small sample size. Hill AFB, Utah was eliminated because it was located with its repair facility. Eglin AFB, Florida was eliminated because it was predominately a research and development center. The five bases included in our study had large sample sizes, were active operational wings, and were not located with their repair centers. Our study included: Eielson AFB, Osan AB, Moody AFB, Ramstein AB, and Shaw AFB.

To further our understanding of the Base Processing Segment and its subprocesses, it was necessary to visit one of the bases included in our study. Of the five bases, Moody was the most interested in participating in the research. Four important aspects of our research were accomplished as a result of visiting Moody. First, we were able to validate the data collection system established to accumulate F-16 reparable asset flow times. Second, we determined the start and stop points for the subprocesses. Third, we identified the Assignable Causes of variation that impact the process. Finally, we used the data and information collected at Moody to enhance the degree of belief in our simulation model. Baseline flow time values entered in our model were based on the Moody data.

Base Processing Segment

A two-step approach was employed to define the Base Processing Segment. This analysis answered our first investigative question. In step one, the depot-level reparable pipeline and its individual segments were validated by a thorough review of current literature. This validation culminated with a description of the Base Processing Segment in sufficient detail to allow for quantitative data collection and analysis. Our description can be found in the following paragraph. In step two, direct observation of base-level reparable asset processing actions at Moody AFB provided an operational understanding of the Base Processing Segment. By focusing attention on the Base Processing Segment, an increased awareness of the subprocesses was gained and appropriate start and stop points for measuring flow times were established. Identification of asset flow through the process enabled us to use SPC. Additionally, it made it possible to build a simulation model (used in the one-factor experiment) that represented the Base Processing Segment.

We found the Base Processing Segment to be comprised of three separate but interdependent subsegments: Maintenance-To-Supply, Supply Processing, and Supply-To-Transportation. As shown in Figure 12, retrograde reparable assets enter the Base Processing Segment at the maintenance shop where they are tested and identified as Not Reparable This Station (NRTS). From maintenance, the assets proceed to supply where accountable inventory records are updated. Finally, the asset is moved to transportation where the asset is prepared for shipment off base. Assets exit the Base

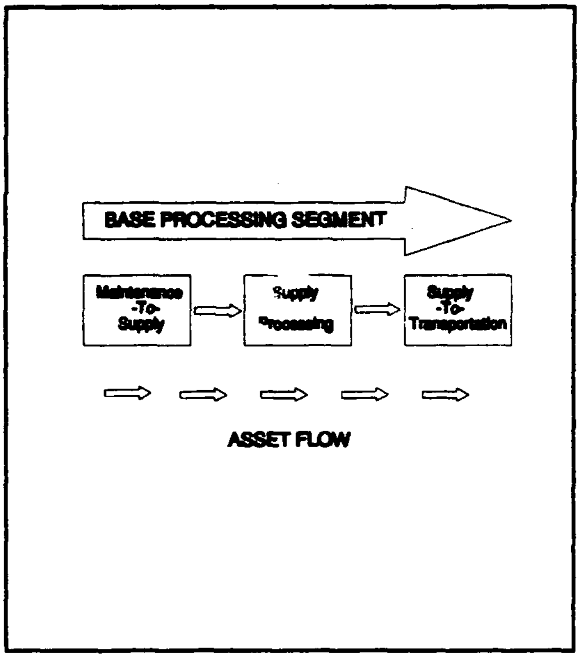


Figure 12. Base Processing Subsegments

Processing Segment when transportation receives the asset from supply. However, before we can improve the flow of retrograde reparable assets, we must understand what the voice of the process tells us. If the process displays controlled variation, it will be stable and consistent. If the process displays uncontrolled variation, it will be both inconsistent and unstable (29:6-7). The next section describes the four possible states of statistical control.

Wheeler's Paradigm

Wheeler stresses that progress toward continual process improvement is measured by how one answers two benchmark questions. First, is the process producing 100% conforming product? And second, is the process achieving a required level of statistical control? By answering these two benchmark questions, it becomes possible to characterize every process (Figure 13) as being in one of four states of statistical control (29:12).

The Ideal State. The preferred state is the Ideal State. In this state, the process is producing 100 percent conforming product and is in statistical control. Conforming product refers to every item produced or every product flowing through the process will be within the desired standards. A process attains the Ideal State only by satisfying, and continuing to satisfy, four conditions:

1. The process must be inherently stable over time.

	Some Nonconforming Product Produced	100% Conforming Product Produced
Process Displays Control	Threshold State - PROCESS IN CONTROL - SOME NONCONFORMING PRODUCT - MUST EITHER... Change process, or Change specifications - Sorting is only a temporary fix - Control Charts Maintain process in control Evaluate efforts at improvement	Ideal State - PROCESS IN CONTROL - 100% CONFORMING PRODUCT - Control Charts Maintain process in control Give timely warning of any troubles
Process Displays Lack of Control	State of Chaos - PROCESS OUT OF CONTROL - SOME NONCONFORMING PRODUCT - Assignable Causes still dominate - Random fluctuations due to Assignable Causes will eventually frustrate efforts at process improvement - The only way out of chaos is to first eliminate the Assignable Causes	Brink of Chaos - PROCESS OUT OF CONTROL - 100% CONFORMING PRODUCT - All may seem okay, but... - Assignable Causes determine what is produced by the process - Quality and conformance can change in a moment

Figure 13. The Four Possibilities for Any Process (29:15)

2. The manufacturer must operate the process in a stable and consistent manner. The operating conditions cannot be selected or changed arbitrarily.

3. The process average must be set and maintained at the proper level.

4. The natural process spread must be less than the specified tolerance for the product. (29:12)

The key to keeping the process in the Ideal State is continuous monitoring of the process to identify problems before they result in nonconforming product. Control charts are used to monitor the process. A detailed discussion of the development and analysis of control charts is presented later in this chapter.

<u>The Threshold State</u>. In this state, the process is in statistical control, but it is producing some nonconforming product. When this condition exists, management must either change the process or change the output specifications to eliminate the nonconforming product. Control charts are the only tool that will help in moving the process from the Threshold State to the Ideal State (29:13). Regardless of what management decides to do, control charts provide the necessary feedback on which to base further actions.

<u>The Brink of Chaos</u>. Processes on the Brink of Chaos produce 100% conforming product, but they are not in statistical control. While on the surface this situation appears acceptable, it is not likely to last. "...For the fact that the process is out of control means that the pattern of variation in the product stream is inconsistent

over time." (29:14) A process in this state is and will continue to be subject to the effects of Assignable Causes of variation. Unless the Assignable Causes are eliminated, the process is unpredictable and can produce nonconforming product at any time. "The only way to move out of the Brink of Chaos is to first eliminate the Assignable Causes. This will require the use of control charts." (29:13-14)

The State of Chaos. In the State of Chaos, processes are out of control and produce some nonconforming product. This state becomes particularly distressing for management because nonconforming product is being produced and predicting when this condition will occur is impossible. No matter what the manager does to correct the situation, Assignable Causes of variation continue to influence the process. The way out of the State of Chaos is elimination of the Assignable Causes of variation. This can be accomplished through the use of control charts (29:16).

The Effect of Entropy. The natural tendency of any process is to deteriorate over time. The force that moves processes in this downward direction is called entropy (Figure 14). According to Wheeler, "every process will naturally and inevitably migrate toward the state of chaos." (29:16) Therefore, the effects of entropy must be continually monitored and countered by process improvement. "...If the effects of entropy are not repaired, it will come to dominate the process, and force it inexorably toward the State of Chaos." (29:16)

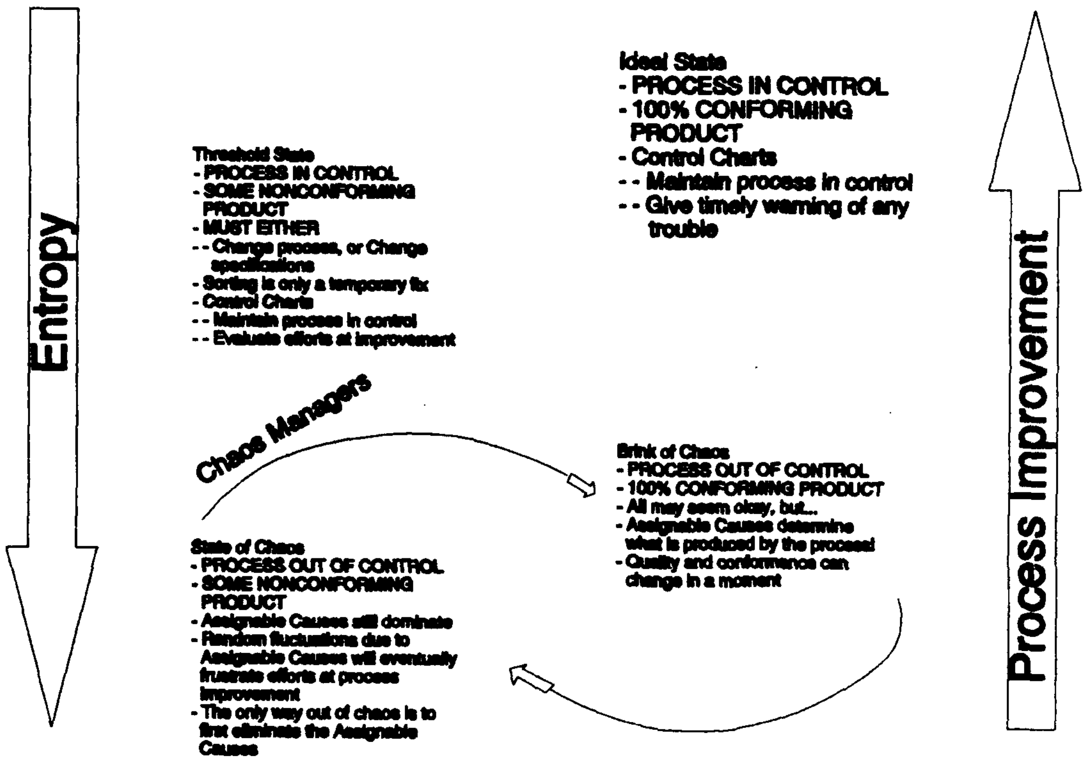


Figure 14. The Effect of Entropy (29:17)

The Cycle of Despair. The Cycle of Despair is the vacillation of a process between the State of Chaos and the Brink of Chaos. In this cycle, the process is moved up to the Brink of Chaos and as soon as management's attention is diverted, entropy sets in and moves the process back to the State of Chaos. This condition frequently occurs because the focus of management is on conformance to specifications instead of the process (29:17-18). Why might this occur? Because conformance to specifications may be attained through product rework and/or labor overtime. Meanwhile, the necessary process improvements required to initially produce within the desired tolerances do not get implemented and the managers contend that they are always too busy.

The Only Way Out. "There is only one way out of this Cycle of Despair. There is only one way to move a process up to the Threshold State or the Ideal State--the effective use of Shewhart's control charts." (29:18) A manager will never truly understand and get the full potential from his processes until he identifies both the effects of entropy and the presence of Assignable Causes of variation (Figure 15). The manager requires process feedback, and control charts are the only tool that will provide this type of information. "Control charts are the only way to break out of the Cycle of Despair." (29:18)

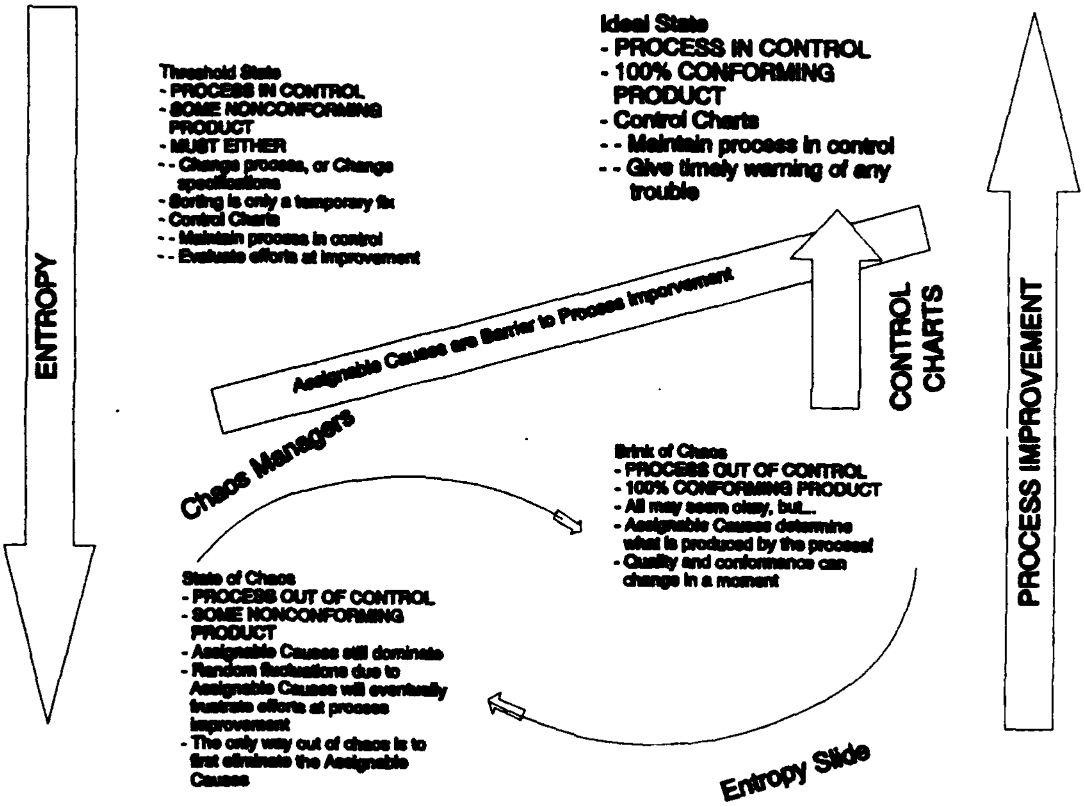


Figure 15. The Only Way Out (29:19)

SPC Application

With a goal of continual process improvement, progress toward this goal is measured with control charts. "The control chart becomes a powerful tool for continual improvement only as those involved with the process learn how to use the chart to identify and remove Assignable Causes of uncontrolled variation" (29:20). Several logical steps are necessary for applying SPC. They are:

1. Choose the characteristic to be charted
2. Choose the type of control chart.
3. Decide the centerline to be used and the basis of calculating the limits.
4. Choose the rational subgroup.
    a. Each point on a control chart represents a subgroup (or sample) consisting of several units of product. Subgroups should be chosen so that the units within a subgroup have the greatest chance of being alike and the units between subgroups have the greatest chance of being different.
5. Provide the system for collecting the data.
6. Calculate the control limits and provide specific instructions on the interpretation of the results and the actions which are to be taken. (5:105)

Step One - Choose the Characteristic to be Charted.

The charted characteristics were retrograde reparable asset flow times. As reparable asset failures occurred on the aircraft, a remove and replace maintenance action was accomplished. The removed asset then entered the Base Processing Segment of the depot level reparable pipeline and thus began our interest in the item. Each reparable asset was represented by a unique supply document number. For the Moody AFB analysis presented later in this chapter, problems associated with a particular item were traced by the document number.

<u>Step Two - Choose the Type of Control Chart</u>. Average (X-bar) and Range (R) SPC charts were constructed and analyzed to determine if the base processing segment was under statistical control. These charts were selected because the X-bar chart monitors the variation in the sample means and the Range chart monitors the variation in sample ranges. In practice, the X-bar chart and the Range chart, as shown in Figure 16, are used together to monitor mean and range simultaneously. An important reason for dealing with them simultaneously is that the control limits of the X-bar chart are a function of the range. "...Average and the Range Charts provide powerful summaries which separate the routine variation from that which is likely to be due to Assignable Causes" (29:52). The purpose of a control chart is to detect out of control conditions.

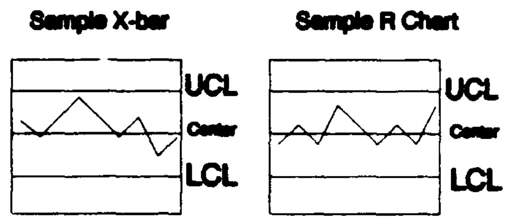


Figure 16. Sample Control Charts

Step Three - Decide the Centerline to be Used and the Basis of Calculating the Limits. Centerline and control limits for the subgrouped data (discussed later) were calculated by Statistix 4.0 computer software. Additionally, this software was used to construct the control charts (28). For the Range Chart, the centerline is computed by taking the averages of the subgroup ranges (R-bar). The Lower Control Limit for the R Chart is calculated as $LCL_R = (D_3)(R\text{-bar})$, where D_3 is a constant based on sample size. The Upper Control Limit for the R Chart is calculated as $UCL_R = (D_4)(R\text{-bar})$, where D_4 is a constant based on sample size. A sample control chart with the LCL, centerline, and UCL is shown in Figure 17.

Calculations for the Average Chart (X-bar Chart) differ from the R Chart; however, the physical appearance of the charts is similar. The centerline for the X-bar Chart is computed by taking the average of the subgroup averages. The LCL for the X-bar Chart: $LCL_x = X - A_2R$. Calculations for the UCL: $UCL_x = X - A_2R$. In both equations, A_2 is a constant based on sample size. The control limits (UCL and LCL) for both the R and X Charts

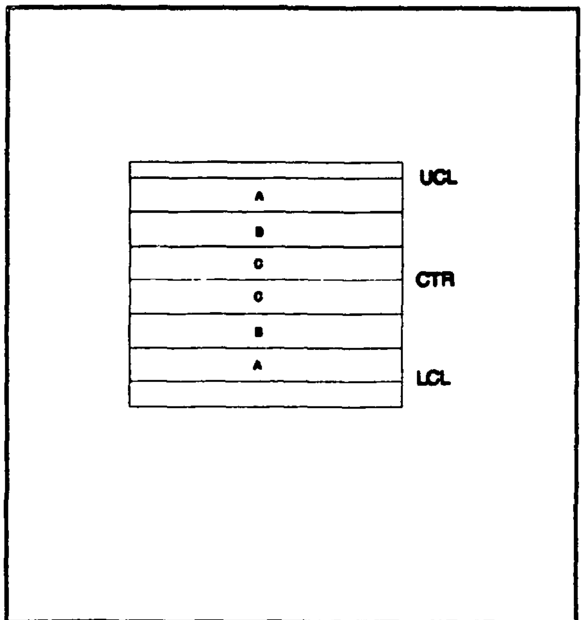


Figure 17. Control Chart

are plus or minus three standard deviations. Additionally, zones were established in one standard deviation increments. These zones are not shown on the Statistix printed control charts, but the zones were used in control chart analysis. A more detailed presentation of the control chart formulas are shown in Appendix A.

Step Four - Choose the Rational Subgroup. For all of the control charts, data points were subgrouped together in the order in which they occur. Our objectives were to give the maximum chance for the measurements in each sample to be similar as well as the maximum chance for the samples to differ (15:735). Table 1 lists by subsegment the subgroup size and sample size for each location.

Step Five - Provide the System for Collecting the Data. We conducted in-depth personal interviews with base-level supply managers at Moody AFB, Georgia to determine how managers collect data on reparable asset flow times in the base processing segment. Personal interviews were conducted with base-level supply managers at Moody AFB and their data collection methods and uses of the data were documented. Interview questions (Appendix B) allowed us to focus the respondents' opinions on current data collection systems and management's use of the data. This review of Moody's data collection system uncovered two important facts. First, flow time data for the Base Processing Segment is used by managers to monitor the average time it takes for an asset

TABLE 1

SUBGROUP AND SAMPLE SIZE

Base	NSN	Subgroup Size	Sample Size
Moody	All	5	175
Shaw	All	5	140
Osan	All	2	48
Ramstein	All	5	105
Eielson	All	2	48

FOR MOODY AFB ONLY:

Subsegment: Maintenance-to-Supply

NSN	Subgroup Size	Sample Size
All	5	175

Subsegment: Supply Processing

NSN	Subgroup Size	Sample Size
All	5	175

Subsegment: Supply-to-Transportation

NSN	Subgroup Size	Sample Size
All	5	175

to transit the system. Control charting is not a management tool currently being used at Moody AFB, at least not in the Base Processing Segment. Second, the data collection system set up to record CORONET DEUCE flow time data is in sufficient detail to support SPC analysis, because under the CORONET DEUCE program flow time data were manually collected for each subsegment of the Base Processing Segment of the depot-level reparable pipeline.

Each of the ten units participating in CORONET DEUCE II established a dedicated data collection office and tracking station for monitoring F-16 avionics reparable assets which flowed through their work centers (14,16,24). The data was forwarded to a central database maintained at Hill AFB, Utah. This thesis focuses on data collected in the Base Processing Segment at five of the test bases (Figure 18). Additionally, for Moody AFB, asset flow times were analyzed for the following subsegments (Figure 19):

1. Maintenance-To-Supply
2. Supply Processing
3. Supply-To-Transportation

Historical data were obtained for F-16 reparable avionics items processed during the period 1 October 1992 through 31 December 1992. The Stock Numbers in Appendix C represent the F-16 avionics reparable assets tracked in the CORONET DEUCE II study.

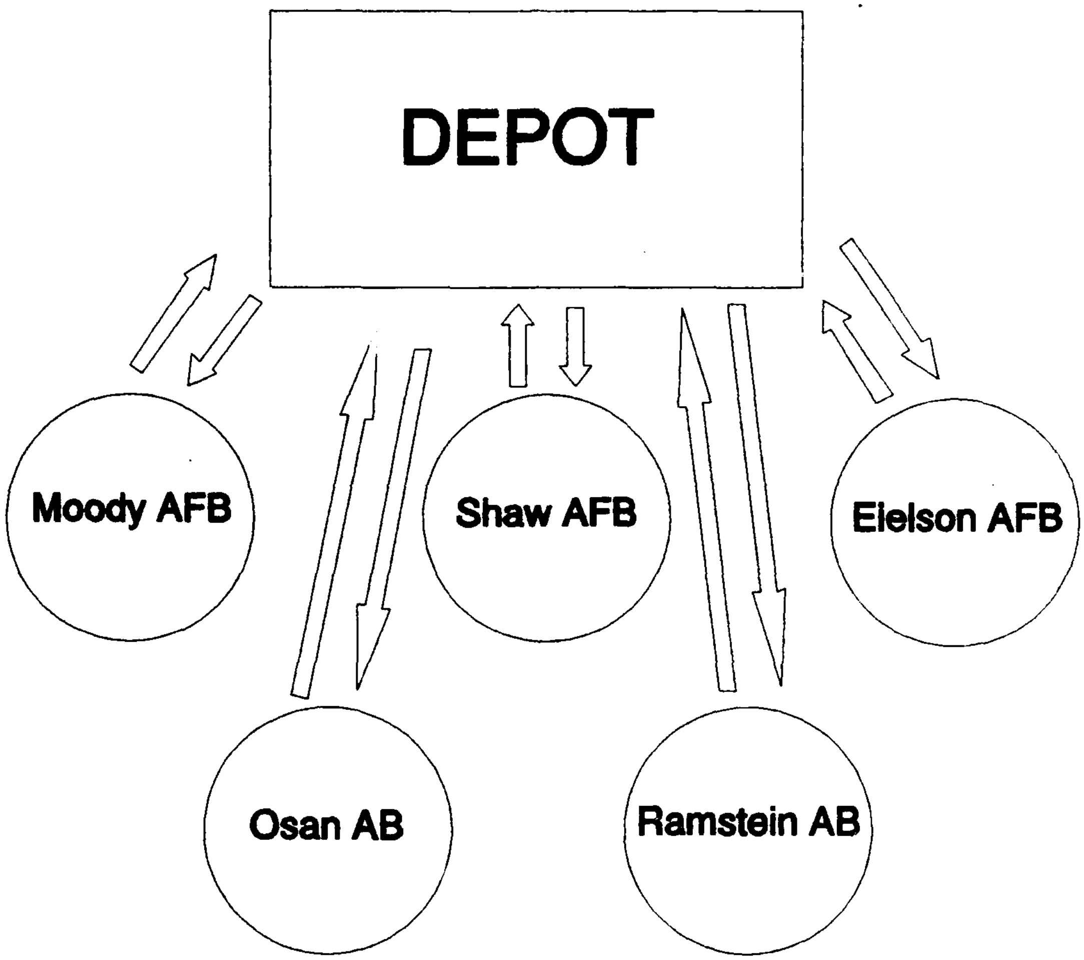


Figure 18. CORONET DEUCE II Reparable Item Flow

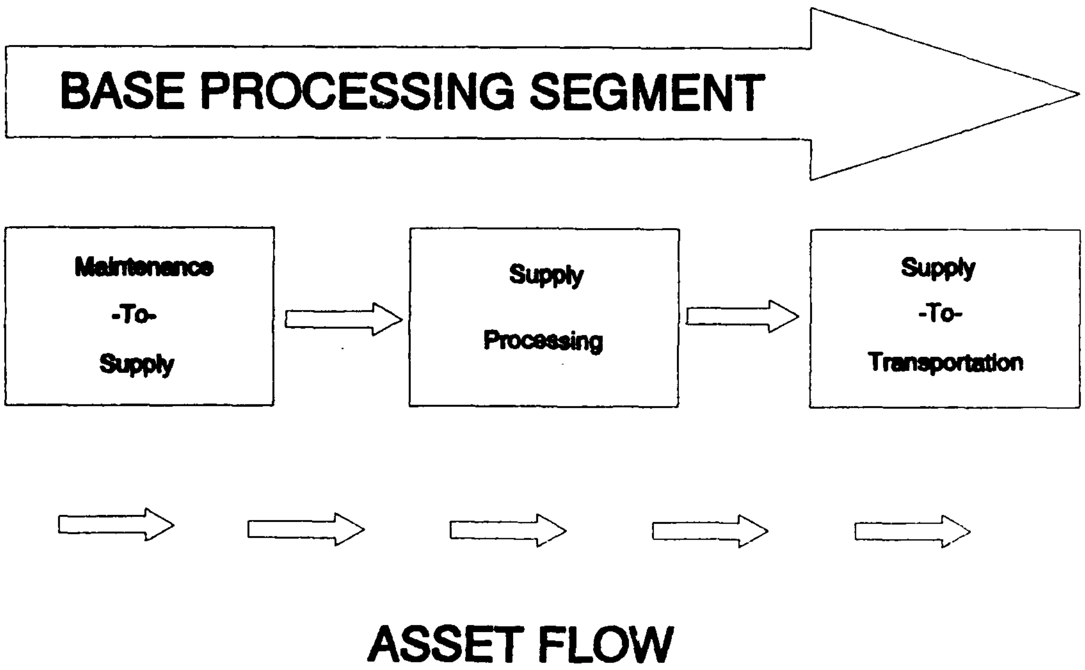


Figure 19. Base Processing Subsegments

<u>Determination of Flow Times</u>. Transaction processing dates and times were used to compute mean flow times for the base processing segment. The mean flow time for the segment is the time from receipt of a reparable part (a bad part is now "owed" to supply), until the part is received by the transportation function. This time was reflected in the CORONET DEUCE II data base as Received date/time and Trans date/time, and was computed by subtracting the Received date/time from the Trans date/time. As we focused our attention specifically toward Moody AFB, the method used for computing the flow times between subsegments was as follows:

1. Maintenance-To-Supply Subsegment: The issue of a replacement reparable item was indicated by a Received date and time in the database. This started the clock for the aircraft maintenance unit to turn-in the unserviceable reparable unit to base supply. The clock stopped when the item was received in base supply. The flow time was computed by subtracting the Received date and time from the date and time the item arrived in supply (see Figure 20).

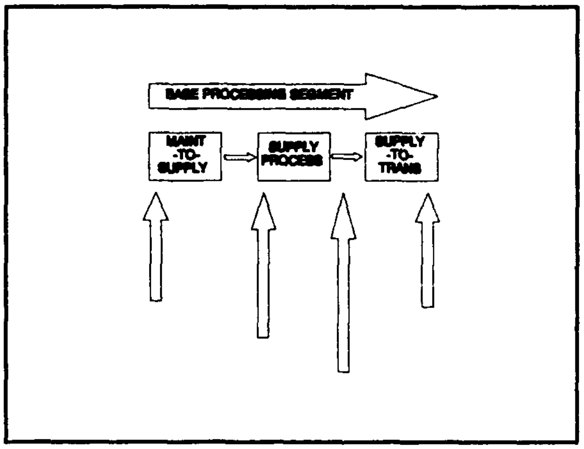


Figure 20. Flow Times

2. Supply Processing Subsegment: Once base supply received the item from maintenance, the item was inspected, prepared for shipment and a turn-in (supply computer transaction) was processed to update accountability. The time for this subsegment started when the item arrived in supply and continued until the reparable item turn-in was processed. Flow time for this subsegment was computed by subtracting the arrived in supply date and time from the turn-in date and time (see Figure 20).

3. Supply-To-Transportation Subsegment: After the reparable item turn-in was processed, the supply computer (SBSS) created a transportation shipping document. The reparable item and its shipping document was moved to the base transportation function by supply personnel. Once the item was received by base transportation, a transportation date and time were entered into the database. Flow time for this segment was computed by subtracting the turn-in date and time from the transportation date and time (see Figure 20). At this point, the reparable item entered the Intransit Segment of the depot-level reparable pipeline departed the Base Processing Segment, and awaits installation departure.

<u>Step Six - Calculate Control Limits and Interpret Results</u>. For each of the five test bases, a centerline and control limits for the subgrouped data were constructed as

outlined in Step Three. The control charts will be interpreted using eight tests contained in Statistix 4.0 Analytical Software (28:287):

Test #1. A point outside the 3-sigma control limits. See Figure 21.

Test #2: Nine points in a row on one side of the center line. See Figure 22.

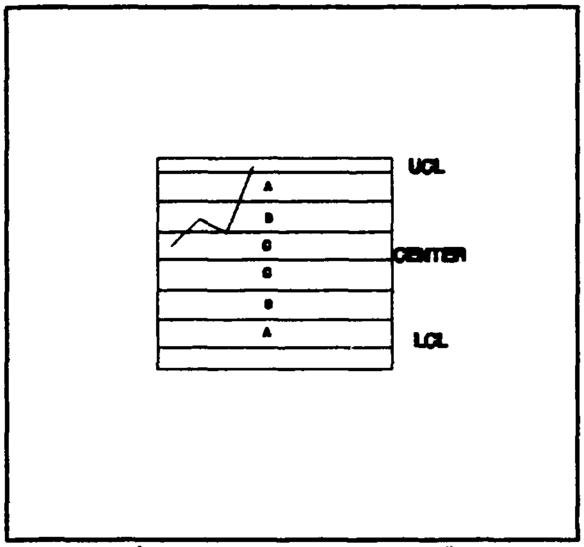


Figure 21. Test #1

TEST #3: Six points in a row, either all increasing or all decreasing. See Figure 23.

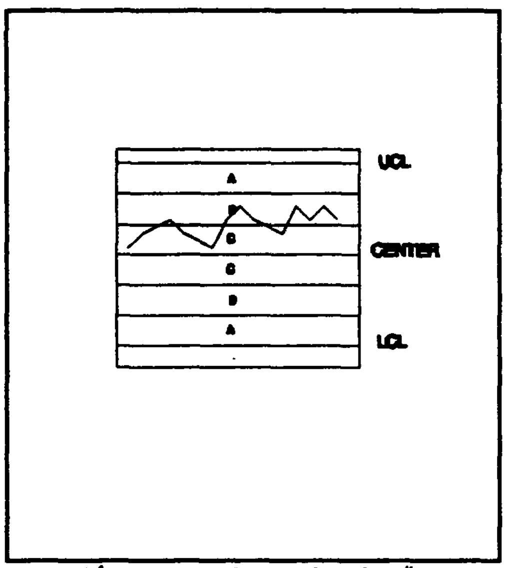


Figure 22. Test #2

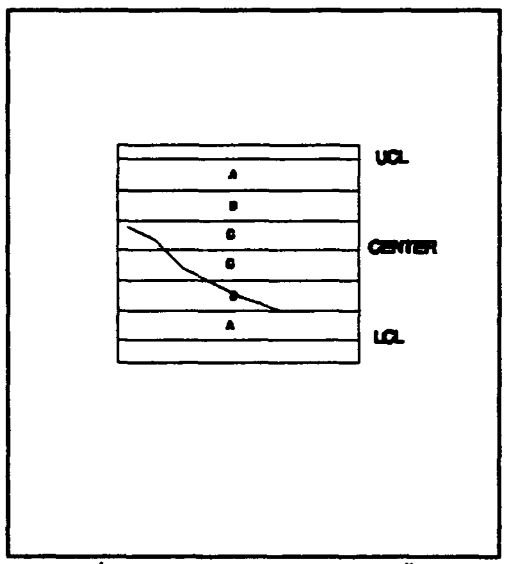


Figure 23. Test #3

Test #4: Fourteen points in a row, alternating up and down. See Figure 24.

Test #5: Two out of three points in a row in zone A or beyond on one side of the center line. See Figure 25.

Test #6: Four out of five points in a row in zone B or beyond on one side of the center line. See Figure 26.

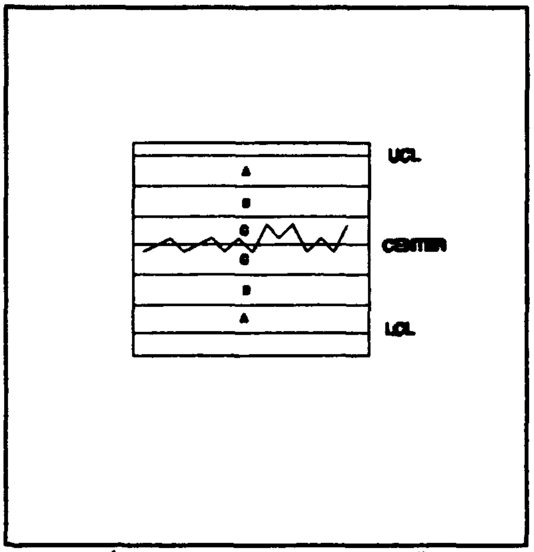


Figure 24. Test #4

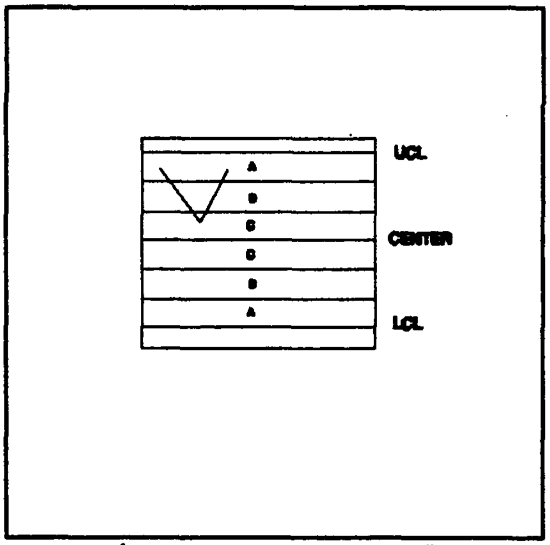


Figure 25. Test #5

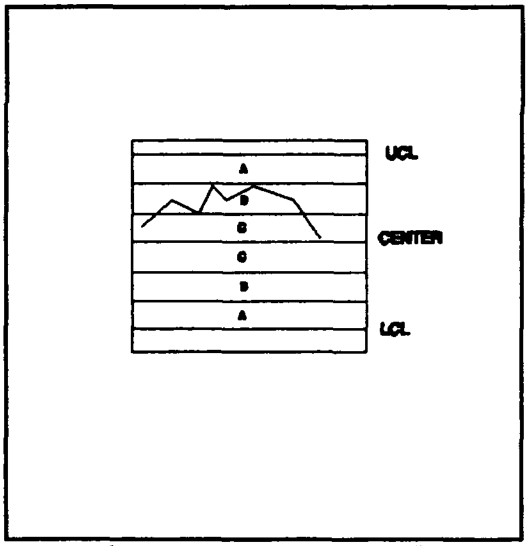


Figure 26. Test #6

Test #7: Fifteen points in a row in zone C on either side of the center line. See Figure 27.

Test #8: Eight points in a row on either side of the center line but none of them in zone C. See Figure 28.

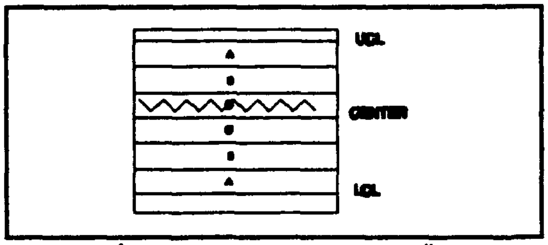


Figure 27. Test #7

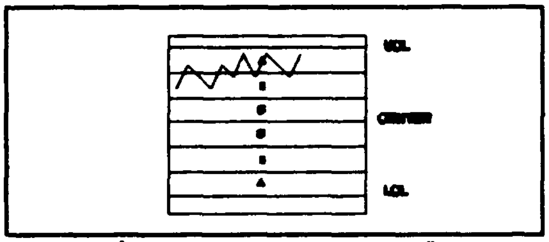


Figure 28. Test #8

These tests are designed to detect pattern shifts in X-bar control charts (28:287). Using the eight detection tests, control charts were analyzed to determine the process status of the Base Processing Segment at each of the five bases. It was beyond the scope of this study to investigate and remove Assignable Causes of variation in five globally dispersed Base Processing Segments. Therefore, only the initial control charts were developed and analyzed for Eielson AFB, Osan AB, Ramstein AB, and Shaw AFB. Assignable Causes of variation were pursued only at Moody AFB. Details of the Moody AFB analysis are developed in the next section. This initial analysis answered investigative question three. Additionally, these detection rules were used to analyze the control charts produced in the one-factor experiment.

Continual Process Improvement

In the context of Wheeler's methodology, continual process improvement centers around the continued use of control charts to monitor a process. Figure 29 shows the

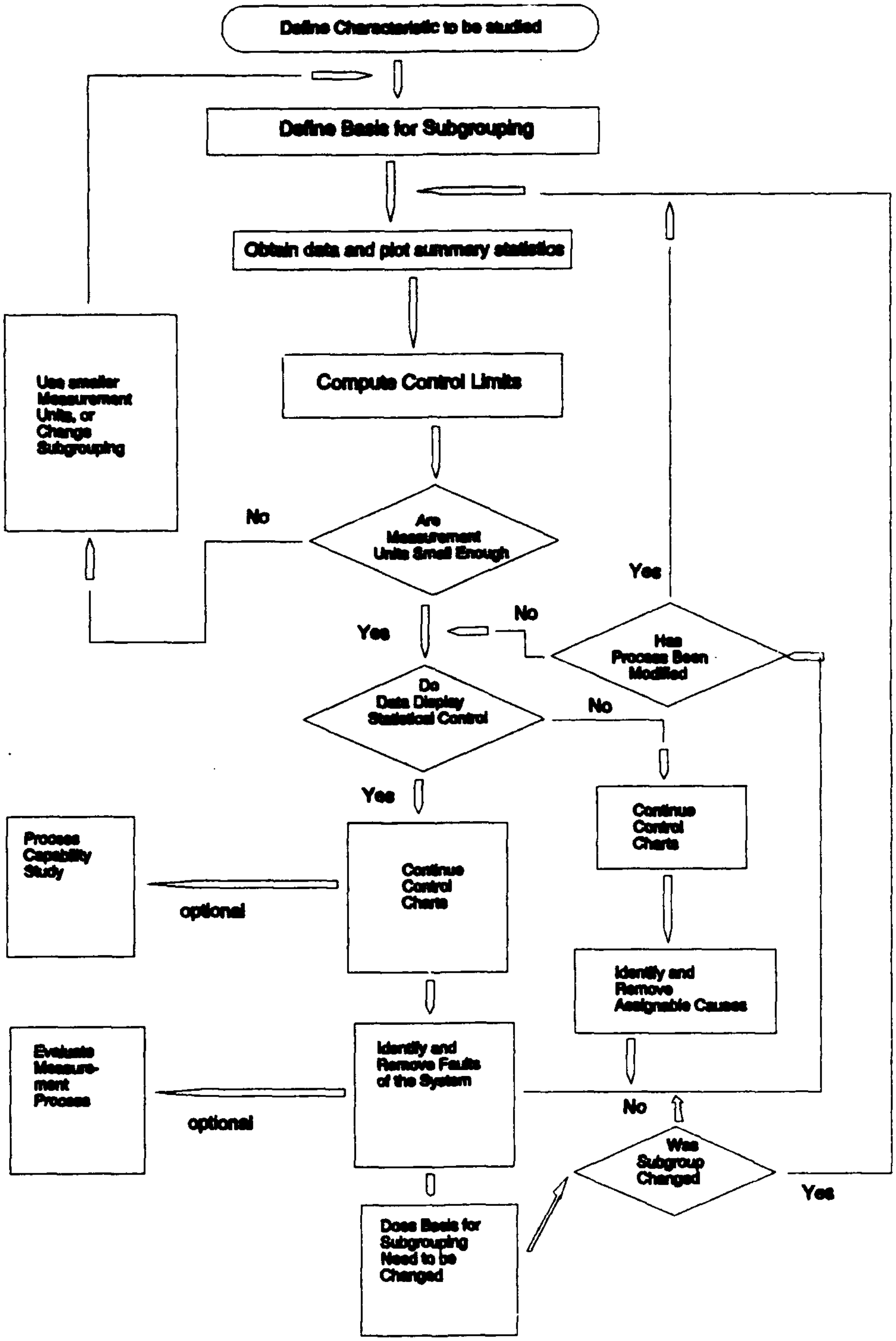


Figure 29. Flowchart for Continual Improvement (29:152)

sequence of decisions and options that are available to help better understand and improve the process. The first step in continual improvement consists of collecting data and maintaining control charts. In step two, the control charts are interpreted and any Assignable Causes of variation are removed. If the process is in control, the control chart can be used to evaluate changes to the process. Step three involves implementation of the knowledge provided by the control chart. "In any company, the ability to move from the point of identifying Assignable Causes to the point of making the necessary changes will primarily depend on the organizational environment" (29:153). We will demonstrate the use of control charting for continual improvement in the context of a one-factor experiment. This method was necessary because our capability to analyze actual (real-time) NRTS asset flow time data from the Base Processing Segment at Moody AFB no longer existed.

For purposes of this thesis, we were afforded an opportunity to visit Moody AFB for three days to conduct interviews and collect information, which made it possible for us to identify Assignable Causes of variation. However, Moody AFB personnel involved with workcenters in the Base Processing Segment do not use control charts to monitor the flow of reparable items throughout the segment or to manage the process. Therefore, needed data is not readily available to analyze variation identified by control charts. Notwithstanding, the continued use of control charts to

Notwithstanding, the continued use of control charts to manage and ultimately improve a process requires the continuous monitoring of performance data for the measurement of progress (29:153). Because additional data was unavailable from Moody AFB, the data that we used to continue control charting and to demonstrate the steps of continual improvement was generated with a simulation model.

Demonstration Methodology. We formulated our continual improvement demonstration utilizing a model for improving quality developed by Moen and Nolan (18:11). The model includes three components: "the development of a charter for the team, a summary of the current knowledge of the team, and the use of an improvement cycle to increase the team's knowledge and to serve as a basis for taking action" (18:11).

Charter. The purpose of this demonstration is to show how control charts can be used to manage the Base Processing Segment (process) and ultimately reduce the flow times of items progressing through the segment. Specifically, this demonstration provides the information necessary to answer investigative question four and research question two. The expected results of the demonstration will show that a particular state of statistical control is not always obvious. A process must be monitored and managed to attain a stable state and remain there. Additionally, this demonstration will show that when a process is in control changes can be made to the process which result in improved performance of the process. The boundary of this demonstration is the existing process of the Base Processing Segment of the depot-level reparable pipeline (18:11-13).

Current Knowledge. The process studied is the flow of retrograde reparable assets through the Base Processing Segment. A detailed presentation of the segment is found in Chapter II and a diagram of the Base Processing Segment is shown in Figure 3. The quality characteristic under study is retrograde asset flow times. As discussed earlier, this characteristic is used to monitor the performance of the process. However, only the average flow time is used to manage and measure performance. In practice, variation in the Base Processing Segment is not monitored. In Chapter IV a cause-and-effect diagram which illustrates the relationship between problems and asset flow times will be presented. A sample cause-and-effect diagram is shown in Figure 30.

General Plan/Improvement Cycle. Earlier in this thesis, we presented detailed analysis of the process under study, the measurement system used for flow time data collection, and the control charts reflecting the flow time data for Moody AFB. Additionally, we presented our analysis of the control charts culminating in an assessment of the state of the process at Moody AFB.

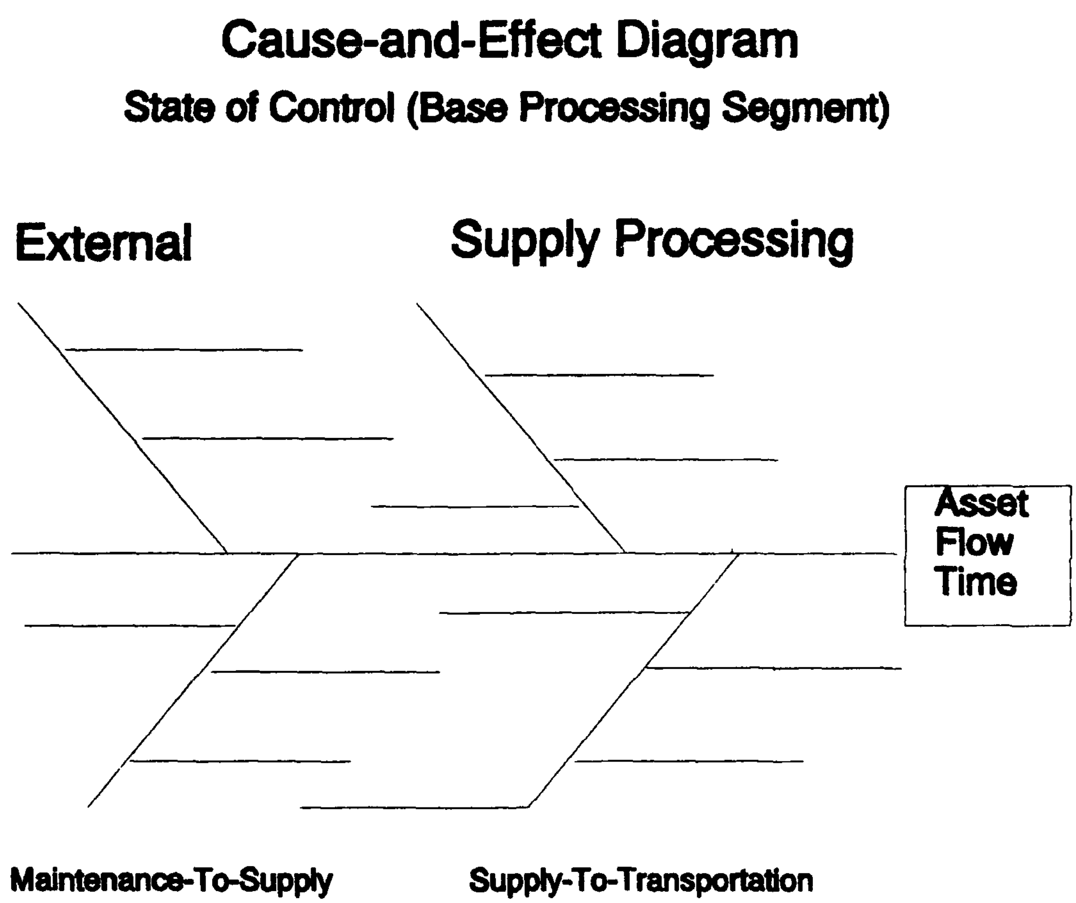


Figure 30. Cause-and-Effect Diagram

We used the flow time average and range calculated from individual data points associated with the final control chart for Moody AFB as our starting values. We generated additional data for control chart analysis. New data streams were created using a GPSS/H simulation model (2). A flowchart of the model is shown in Figure 31. The actual GPSS/H model coding is in Appendix D. Finally, as data was generated, control charts were built and analyzed to depict changes in the state of the process. Histograms were constructed to access the capability of the process when such an assessment was possible (18:18-19). Remember that capability assessment can only be made on processes that display stability.

Demonstration/Experimental Design. Mechanically, our demonstration was developed by using a one-factor experiment. A one-factor experiment was selected because this type of experiment allows the use of control charts to evaluate changes in the process (18:80-90). The experiment parameters will be discussed in Chapter IV. This demonstration does not show, and is not intended to show, actual continuous improvement at Moody AFB. The simulation model was built based on the Base Processing Segment at Moody AFB, and the data used in the model was the result of data collected there. However, the data generated by the model may not represent actual Moody AFB flow time data. Again, Moody AFB personnel do not use control charts to monitor the processes in the Base Processing Segment.

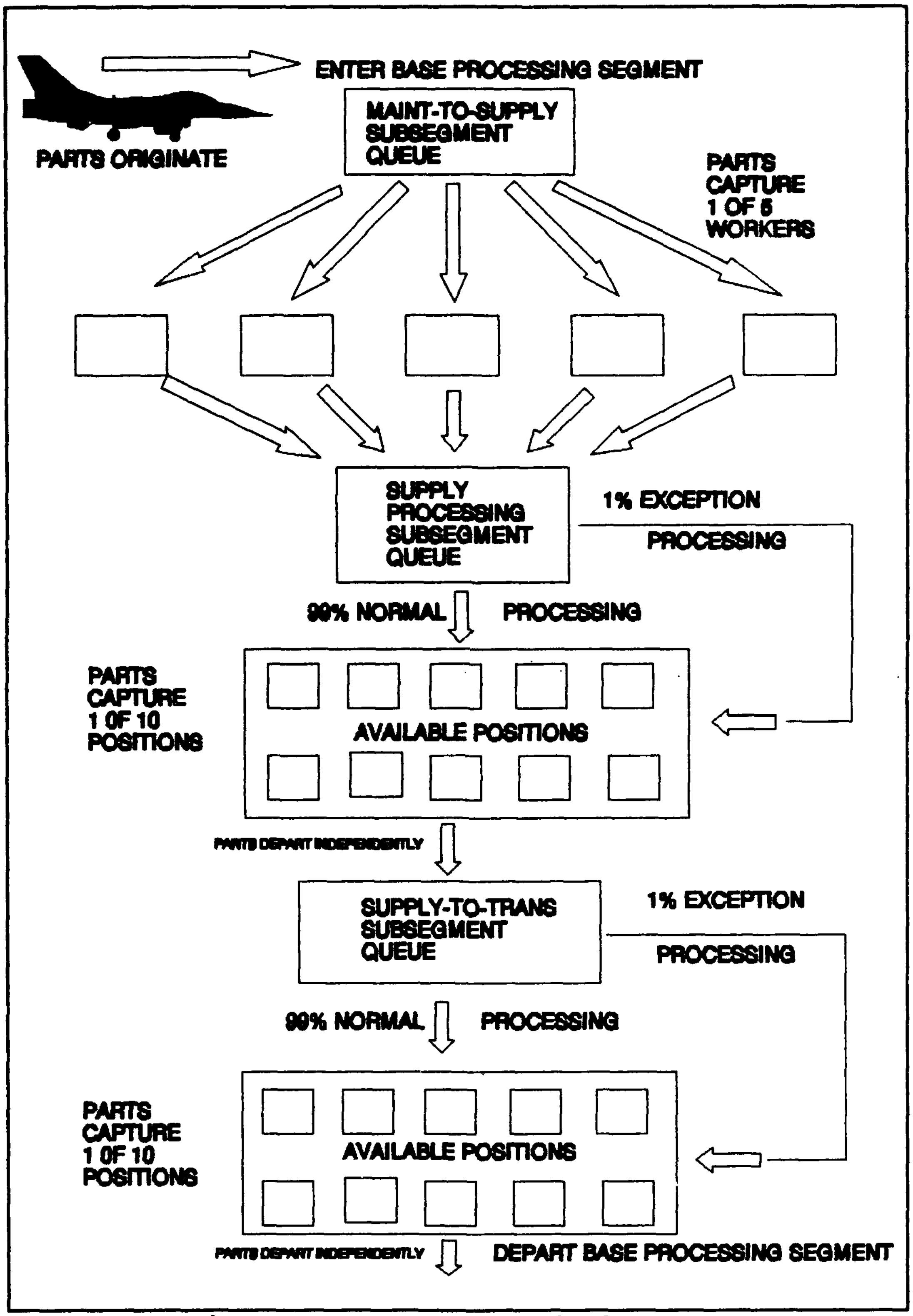


Figure 31. GPSS/H Model Flowchart

This demonstration is only for the purpose of illustrating Wheeler's methodology for continual improvement.

Analysis of Moody AFB Data

To determine how retrograde asset flow data could be used to affect processes and ultimately reduce base processing flow times, we limited our focus to data collected at Moody AFB. We began our analysis with construction of the R and X-bar chart. An R chart measures the variability of the process. If the R chart indicated that the process was in control, we analyzed the X-bar chart. If both charts indicated that the process was in control, no further analysis was conducted. If the process was out of control, we used the following steps to identify and eliminate the Assignable Causes of variation and attempted to bring the process into control:

> ...The points on the control chart that indicate that the process is out of control should be investigated to see if any special causes of variation can be identified. If special causes are found, (1) they should be eliminated, (2) any points on the chart determined to have been influenced by the special causes--whether inside or outside the control limits--should be discarded, and (3) new trial centerline and control limits should be calculated from the remaining data. However, the new trial limits may still indicate that the process is out of control. If this happens, the three steps previously noted should be repeated until all points fall within the control limits.
>
> If special causes cannot be found and eliminated, the severity of the out-of-control indications should be evaluated and a judgement made as to whether (1) the out-of-control points should be discarded anyway and new trial limits constructed, (2) the original trial limits are

> good enough to be made official, or (3) new sample data should be collected to construct new trial limits. (15:740)

Consistent behavior indicated that the process was in statistical control, and inconsistent behavior indicated that the process may have been out of control. Wheeler states, "If the subgroups display consistent behavior, then it is reasonable to assume that the process is not changing over time. If the subgroups display inconsistent behavior, then the process is said to display uncontrolled variation" (29:40). Once process status had been determined for the Base Processing Segment at Moody AFB, the next step was to make a capability assessment of the process.

Moody AFB Capability Analysis

To accomplish a capability assessment of the Processing Segment at Moody AFB, a histogram was initially plotted using individual data values from the control chart. We used the axis of the histogram to show specification limits (see Figure 32). Because the Moody AFB specification limit was 24 hours, we assessed the capability of the process by comparing the Natural Process Limits with the Specification Limits. Once more we referred to Wheeler for guidance:

> If the Natural Process Limits for a stable process fall entirely within the Specification Limits, then the process can be said to be in the Ideal State: it is in control and producing 100% conforming product. Such a process is said to be both stable and capable. If one or both of the Natural Process Limits for a stable process fall

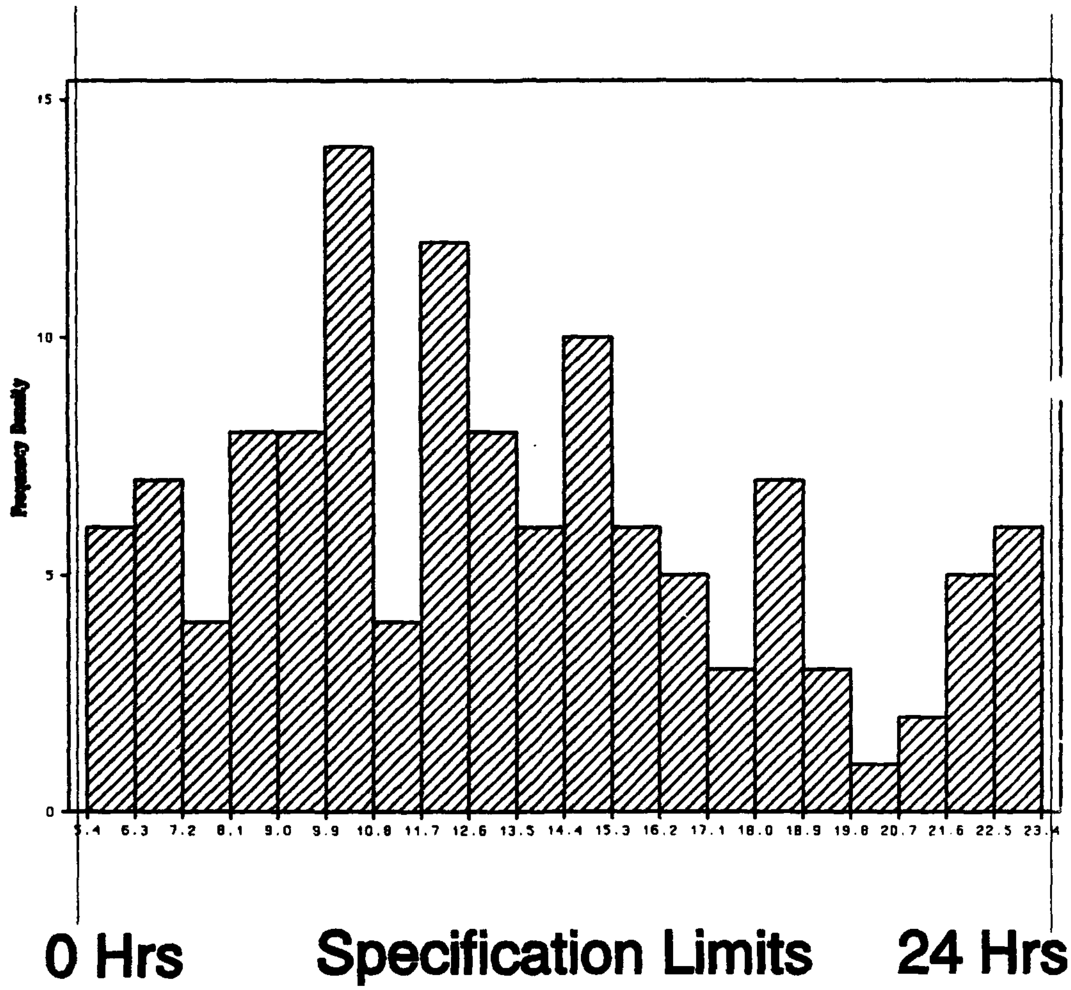


Figure 32. Histogram

> outside the Specification Limits, then the process may be said to be in the Threshold State: it is in control, but it is likely to be producing some nonconforming product. Such a process is stable but not capable. (29:120)

Ideally, process capability analysis would be conducted periodically by collecting data and plotting the data on a histogram. The Natural Limits of the new data would be compared to the Process Specification Limits, based on the above criteria, and a new determination made as to the capability of the process. Because we were using a limited amount of data and did not have access to further data, continued capability assessment of Moody AFB was not possible.

Chapter Summary

This chapter outlined the method that was used to examine process variation of flow times in the Base Processing Segment. It began by describing Wheeler's paradigm, identifying the four possible states of a process: Ideal, Threshold, Brink of Chaos, and Chaos. Next, we presented the procedures for using statistical process control, detailing the six steps for assessing the stability of a process. We showed how to use control charts for continual process improvement by introducing changes to the process mean/variance and then charting the result of our one-factor experiments. And finally, we discussed our analysis of the Moody AFB data and the assessment of Moody's Base Processing Segment capability.

IV. Information and Data Analysis

Overview

This chapter provides the findings from our research conducted and our data analysis in examining the Base Processing Segment of the depot-level reparable pipeline. Our examination focused on base-level retrograde asset management, the effects of process variation on retrograde asset flow times, and how knowledge gained about process variation can be used at base-level to reduce retrograde asset flow times. Research performed at Moody AFB, Georgia included observation of Base Processing Segment activities, examination of applicable regulations, interviews with personnel involved in managing the processes, validation of the collection of flow time data, and identification of Assignable Causes of variation associated with the flow time data collected. Additionally, we examined and tabulated Base Processing Segment flow time data from four other Air Force bases that operate the same type of aircraft. Moody's flow time data was later tabulated, restructured, and used as base line estimates for our active experimentation with control charts. The research answered our four investigative questions:

1. When do assets enter and what actions occur in the Base Processing Segment?

2. What data are collected and how is it used to make managerial decisions about retrograde asset flow?

3. Is the asset movement process within the Base Processing Segment under statistical control?

4. How should management use retrograde asset flow data to continually improve processes and ultimately reduce Base Processing Segment flow times?

Defining the Base Processing Segment of the Depot-Level Reparable Pipeline

The first investigative question was answered by combining an in-depth review of current depot-level reparable pipeline literature with a direct observation of base-level reparable asset processing actions at Moody AFB, Georgia. In our examination, we found the Enhanced Depot-Level Reparable Pipeline Model created by Kettner and Wheatley (Figure 2) accurately described the boundaries of, and the activities within, the Base Processing Segment (13:127-129).

We further detailed Kettner and Wheatley's description of the Base Processing Segment by identifying three separate, but interdependent subsegments from which to measure flow times: Maintenance-To-Supply, Supply Processing, and Supply-To-Transportation (Figure 33). Our pipeline parameter of interest was retrograde asset flow times and we devised the following methods to determine flow times by subsegment:

1. Maintenance-To-Supply Subsegment: The base maintenance unit determines that an item is Not Reparable This Station (NRTS) and places a demand on base supply. When base maintenance receives a serviceable replacement item, the NRTS item (also referred to as retrograde) is owed to a depot-level repair center and the clock starts for determining pipeline flow times. The Maintenance-To-Supply subsegment flow time ends when the retrograde item is received at base supply.

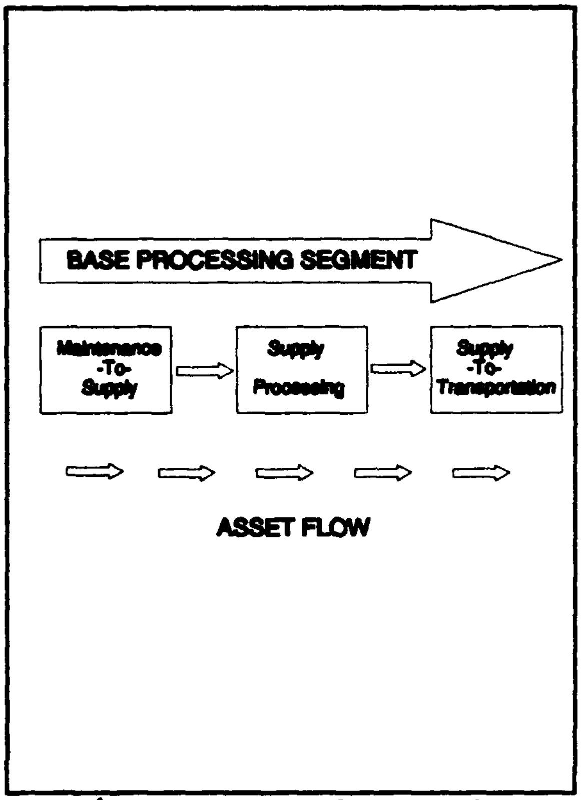


Figure 33. Subsegments

2. Supply Processing Subsegment: Here, the interdependency begins because the ending time of the Maintenance-To-Supply subsegment is also the starting time for Supply Processing. The retrograde item is inspected, prepared for shipment and a Turn-in (supply computer transaction) is processed to update accountability. The Supply Processing subsegment flow time ends when the Turn-in processes in the computer system or when a Turn-in document is completed under manual procedures.

3. Supply-To-Transportation Subsegment: After the retrograde item Turn-in is processed, the supply computer creates a transportation shipping document. This transportation shipping document can also be prepared manually. The retrograde item and its shipping document are moved to the base transportation function by supply personnel. Once the item is received by base transportation, a date and time are annotated on the shipping document. Flow time for this segment is calculated by subtracting the Turn-in date and time from the received by base transportation date and time.

When retrograde items are received by base transportation, they depart the Base Processing Segment of the depot-level reparable pipeline and enter the Intransit Segment. Our interviews with personnel working within the Base Processing Segment activities at Moody AFB confirmed that all retrograde items normally pass through this sequence of subprocesses (6, 12, 16, 21).

Base Processing Segment Pipeline Management

To answer our second investigative question, we examined the collection of data and the information used in managing the Base Processing Segment of the depot-level reparable pipeline. Management information on the activities found within the Base Processing Segment was used both at base level and at headquarters level. We relied on current literature, interviews conducted with personnel working in the Base Processing Segment at Moody AFB, and our own knowledge/experience gained as supply operations officers working in base-level supply activities. Additionally, we reviewed Moody AFB regulations and Air Force directives that applied to Base Processing Segment pipeline management.

Base-Level Pipeline Management. When an aircraft maintenance technician places a demand on base supply to replace a reparable item, a Due-In from Maintenance (DIFM) detail is established in the SBSS computer. This DIFM detail is updated automatically when the replacement item is received by maintenance to indicate that maintenance owes a like item to supply. Pipeline management actions at base-level revolve around satisfying this debt in the SBSS computer records within the average time frames established by operating directives. Interviews with personnel working within Base Processing Segment activities at Moody AFB confirmed that the Reparable Asset Control Center (RACC), also known as the Repair Cycle Support Section, is charged with maintaining accurate computer records of location and status for all retrograde assets in maintenance (6; 12; 16; 21). Our observations indicated that thorough coordination occurs between maintenance and supply technicians to ensure the update of DIFM detail records and expedite the continuous flow of retrograde assets.

Retrograde asset tracking is facilitated by the use of a Repair Cycle Asset Management List (D23) output by the

SBSS computer and provided to maintenance activities on a daily basis. Workers were knowledgeable of pre-established maximum retrograde flow time parameters that communicated management's desire for pipeline performance. These pre-established time frames or goals can be considered upper specification limits when acknowledging retrograde asset flows as processes. For our investigation, we researched CORONET DEUCE (the two level maintenance test program) retrograde item flow times. Traversing the Base Processing Segment in less than 24 hours is the management goal of Air Combat Command for items associated with CORONET DEUCE (6; 12; 14; 16; 24). A breakdown by subsegment is as follows:

Maintenance-To-Supply	20 hours
Supply Processing	2 "
Supply-To-Transportation	2 "
Total	24 hours

Because retrograde assets flowing through the Base Processing Segment cross the organizational boundaries of aircraft maintenance, supply, and transportation, close coordination among first-level supervisors is critical for success. In addition, higher-level coordination is secured at least biweekly when shop chiefs, flight supervisors, and squadron commanders meet to review goal attainment and to address goal busters. The focus of these biweekly meetings is two-fold. First, they review data pertaining to mean flow times achieved in relationship to meeting the 24-hour goal. Next, they provide individual attention to goal busters, the retrograde movements that take more than 24 hours to complete the Base Processing Segment (12; 14; 16; 21; 24). Figure 34 is an example of the visual aid used by base-level managers during one of their biweekly meetings in mid-March. Each DIFM document number on the left side of the visual aid correlates to one and only one retrograde asset. The names across the top of the chart (Org Time, AIS Time, and FSC Time) refer to Organization time, Arrived In Shop time, and Flight Service Center time. Only those items whose total time in the segment exceeds 24 hours are reviewed. The units responsible for delays must be prepared to provide explanations upon demand.

Work centers in the Base Processing Segment at Moody AFB did not use control charts to monitor the flow of retrograde assets through the system. Managers review goal busters and attempt to remedy situations that cause individual flow time values greater than 24 hours (12; 14; 16; 21). If we apply Wheeler's paradigm to this situation as discussed in Chapter 3, his Cycle of Despair becomes evident (29:17-18). Managers are focusing on conformance to specifications instead of focusing on the process itself. While conformance can be attained, the process must be forced through management attention. Recall that the only way out of this Cycle of Despair is the effective use of Shewhart's control charts (29:18). We found that continuous improvement endeavors associated with Quality Air Force were

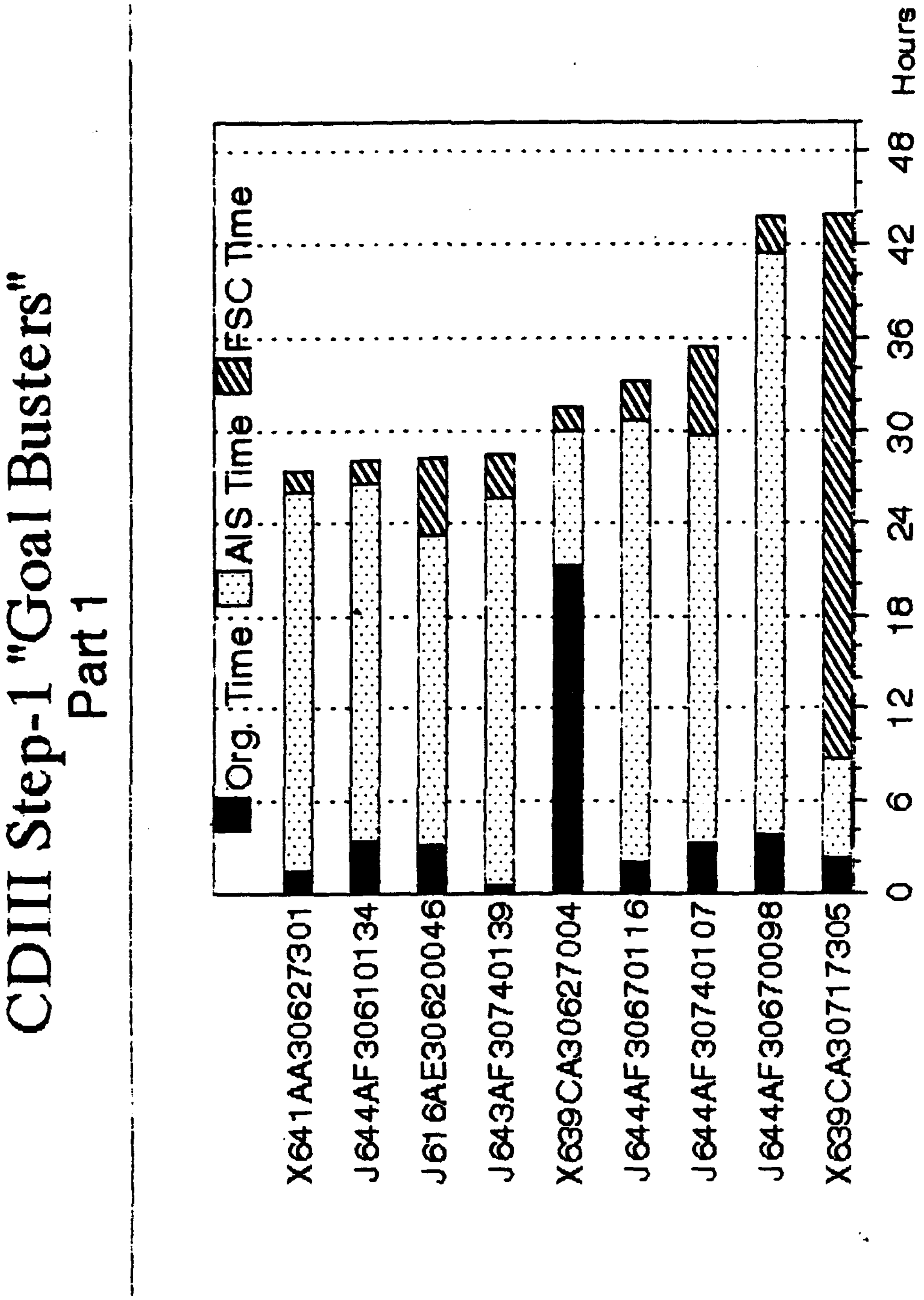


Figure 34. Example of Moody AFB "Goal Buster" Visual Aid

actively being pursued in various activities at Moody AFB. As discussed in Chapter I, there is also a push throughout the DoD to reduce inventory investment. Reducing base-level pipeline flow times through the use of control charts can lead to lower inventory investment and has great potential to become the project of a base project action team.

Headquarters-Level Pipeline Management. The data of interest to managers working at Air Force Material Command (AFMC) is the base processing days component of the reparable pipeline (27:2). Base Processing Segment flow time data for reparable items are automatically collected by the Recoverable Assembly Management Process System (D035C). The D035C receives this base-level information from the Standard Base Supply System (SBSS) computer. As supply technicians process Turn-in transactions on the SBSS computer, a subsequent shipment document is created that accompanies retrograde items to base transportation. Additionally, the SBSS computer creates output images that are electronically transmitted to the D035C subsystem. Because the D035C subsystem is also notified when the reparable items are issued from SBSS stocks, computing base processing days reduces to simple date-and-time subtractions.

An important function of the D035C is the computation of average base processing days flow time data. This average or mean flow time data is subsequently provided to the Recoverable Consumption Item Requirements System (D041).

Managers working at AFMC use the D041 to compute the number of reparable assets needed at the wholesale level to meet Air Force spares requirements. Therefore, AFMC pipeline managers focus on mean flow times when analyzing and determining reparable asset requirements information. Headquarters-level pipeline managers do not consider the effects of variation in the Base Processing Segment of the pipeline. Large flow time values resulting from Assignable Causes of variation can push mean flow time values beyond what the Voice of the Process is trying to communicate. As a result, these inflated mean flow time values may lead to unnecessary acquisition actions.

Statistical Control Assessment of the Base Processing Segment

To answer our third investigative question, control charts were used passively to provide feedback on the retrograde asset movements of five Air Force bases that participated in the CORONET DEUCE test program. Our purpose was to assess each Base Processing Segment and classify the retrograde item movement process into one of Wheeler's four states of statistical control.

General Analysis of Base-Level Flow Times. We began our statistical control evaluation by running R charts and X-bar charts for Eielson AFB and Osan AFB. Both bases had equivalent sample sizes of 48 and were subgrouped by 2. Next, R charts and X-bar charts were run on the three remaining bases (Moody, Shaw, and Ramstein) that had larger sample sizes and were subgrouped by 5. The results from our control charting are summarized in Table 2 and the actual control charts can be found in Appendix E.

TABLE 2

SUMMARY OF BASE PROCESSING SEGMENT CONTROL CHARTS

Base	R Chart Classification	X-bar Chart Classification	Wheeler's State
Eielson	In Control	Out of Control	State of Chaos
Osan	Out of Control	Out of Control	State of Chaos
Moody	Out of Control	Out of Control	State of Chaos
Shaw	Out of Control	Out of Control	State of Chaos
Ramstein	Out of Control	Out of Control	State of Chaos

Of all our initial control charts, only the R chart associated with Eielson AFB's retrograde asset flow times was found to be in statistical control. All 5 bases were found to be in Wheeler's State of Chaos. Recall from Chapter 3 that in the State of Chaos, processes are out of control and produce some nonconforming product. To assess each of the 5 bases equitably, conforming product was based on the 96 hour Air Force goal rather than using the various major command or base-level goal. All of the Base

Processing Segment flow time data was used as it existed in the CORONET DEUCE data base. Recognizing that CORONET DEUCE flow times included Assignable Causes of variation, we traveled to Moody AFB, Georgia to validate the collection of data and to identify as many of the Assignable Causes of variation as possible.

Specific Analysis of the Base Processing Segment at Moody AFB. As discussed in the previous section, our first step in general analysis was to construct and interpret an R chart. Figure 35 shows the initial R chart and X-bar chart for the Moody AFB Base Processing Segment. There are six out of control conditions indicated on the R chart by subgroups: 16, 21, 25, 29, 32, and 33. These subgroups are out of control because they violate test one, a point outside the three-sigma control limit. Within subgroups 16, 21, 25, and 29, we found items that were not part of the CORONET DEUCE program and did not belong in our sample. Subgroups 32 and 33 included items flowing through the segment during the Christmas holiday period when manning levels were reduced to a minimum and not representative of normal processing. Subgroups associated with Assignable Causes of variation were removed.

Figure 36 is a reconstruction of Moody's initial control charts with subgroups associated with Assignable Causes removed. There are two out of control conditions indicated on the chart. Both of the out of control conditions are due to failing test one. Our investigation

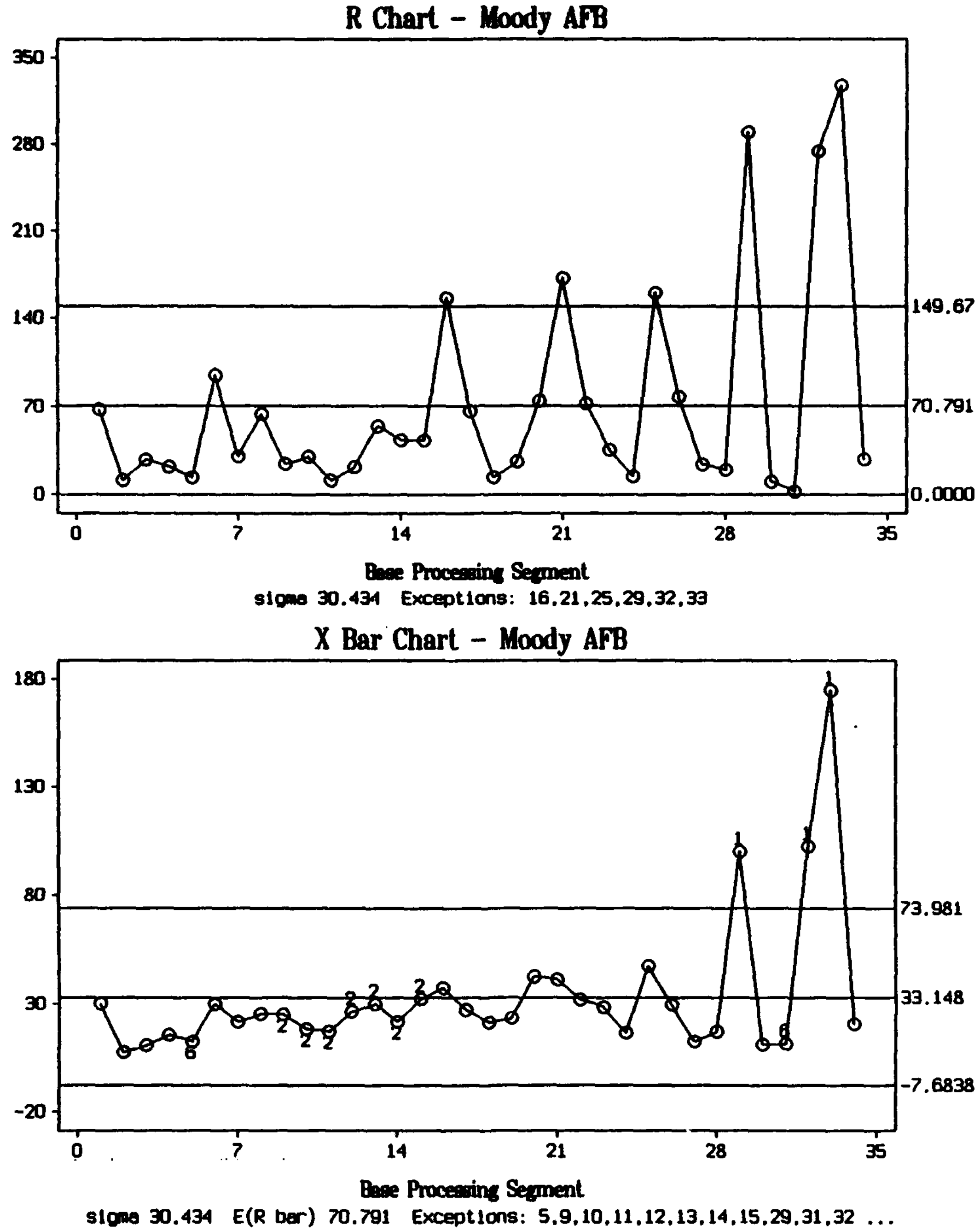
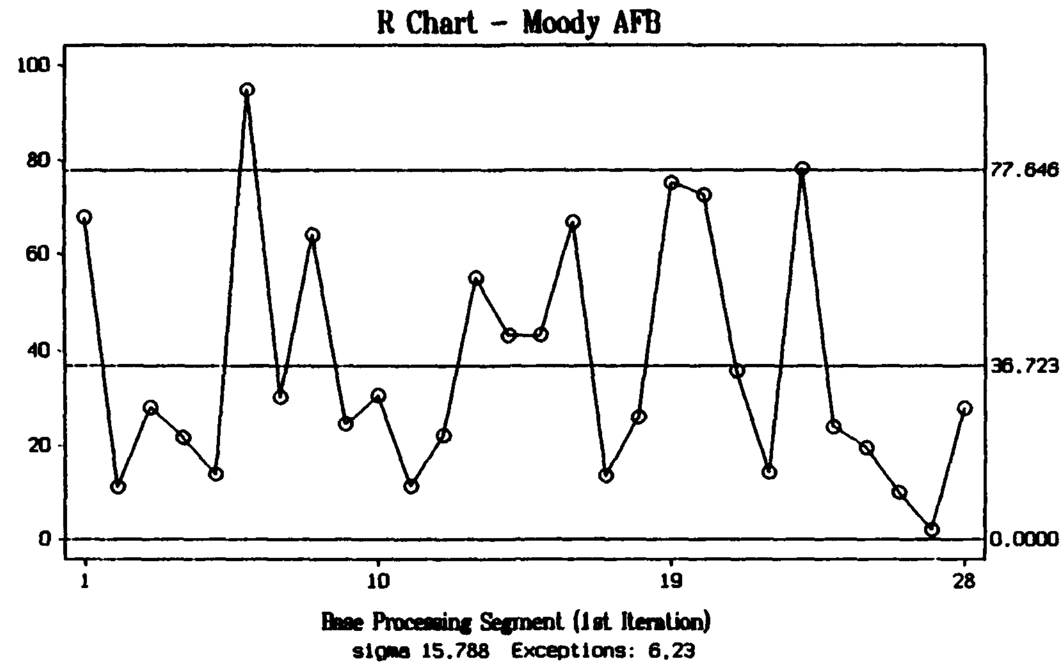


Figure 35. Initial Charts for Moody AFB



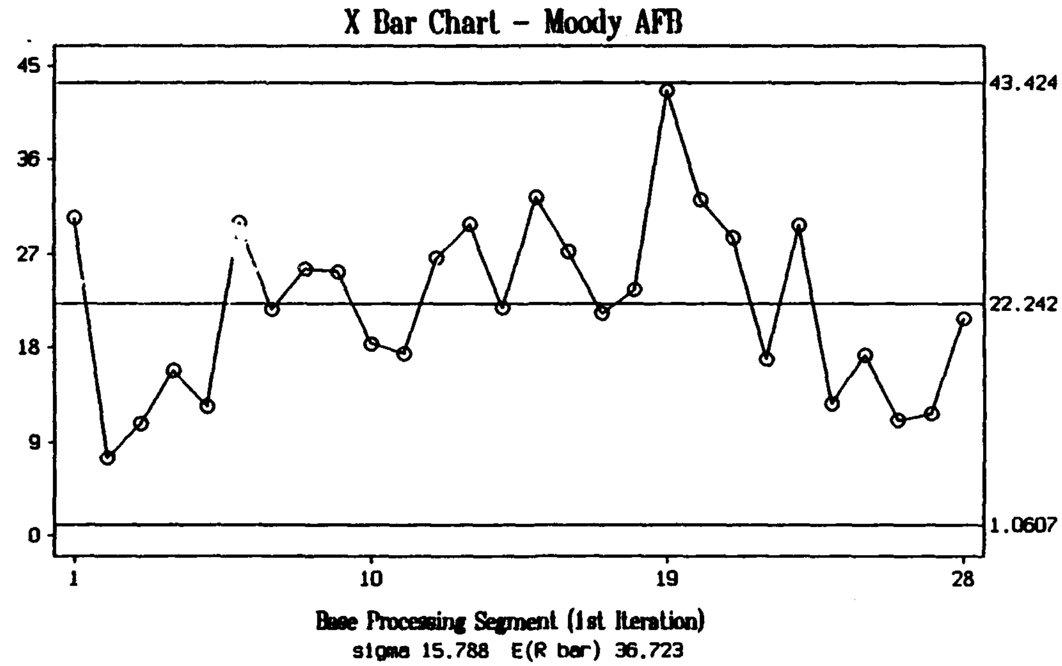
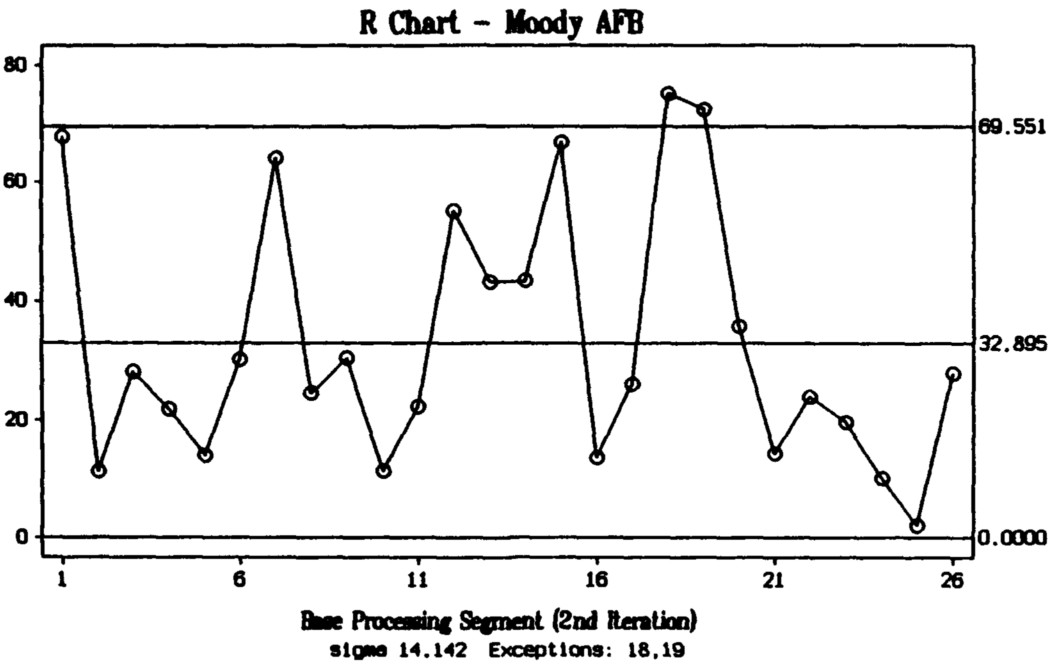


Figure 36. Charts for Moody AFB, 1st Iteration

revealed that both conditions resulted from retrograde items being held while the mainframe computer system was down. Personnel working in the system did not proceed with manual processing procedures. Because these delays were attributed to an Assignable Cause, the two out of control subgroups were removed.

After removing subgroups containing Assignable Causes of variation, a new set of R and X-bar charts were run. Our Moody AFB Iteration #2 charts can be found in Figure 37. The control chart analysis indicated subgroups 18 and 19 were outside of the three-sigma limit and failed due to test one. Researching into subgroup 18, we found that for one item maintenance experienced a test station failure and the retrograde asset was delayed. Subgroup 19 items were held over the Thanksgiving holiday weekend due to work center closures. These conditions were due to Assignable Causes of variation and their subgroups were removed.

A new set of control charts was once again produced and can be located at Figure 38. In this R chart, out of control conditions were found in subgroups 1, 7, and 15. Subgroups 1 and 7 failed test one and were outside the upper control limit. We discovered that base transportation was closed and items in each subgroup were held at supply. Subgroup 15 contained two items that were mistakenly held in the maintenance shop over a weekend. Our identification of these Assignable Causes led us to remove subgroups 1, 7, and 15 from our data base.



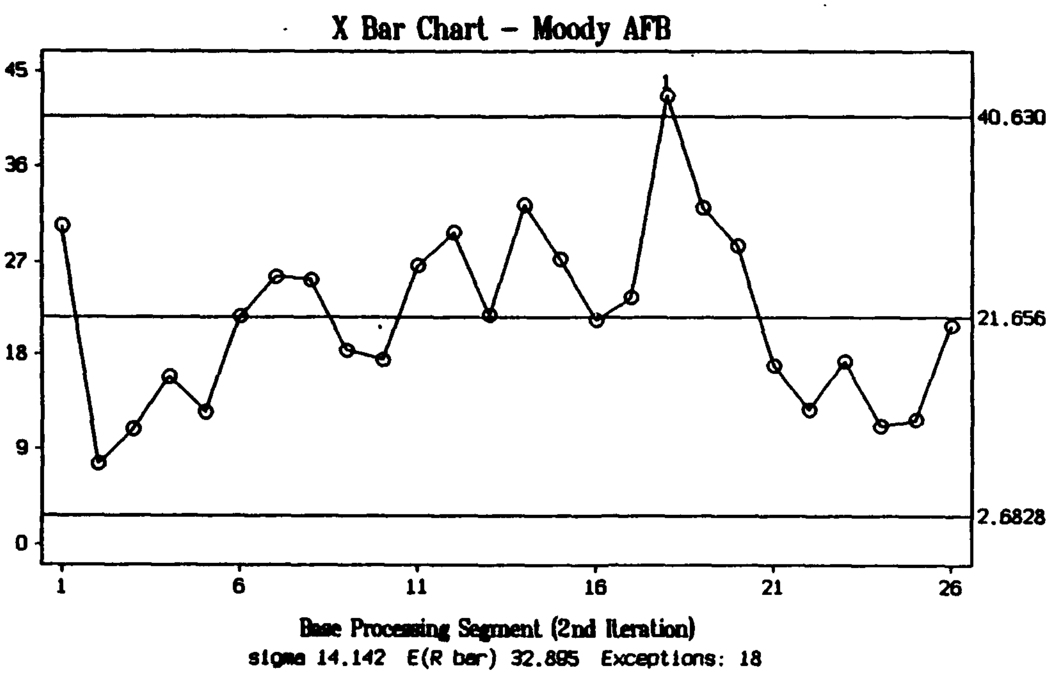


Figure 37. Charts for Moody AFB, 2nd Iteration

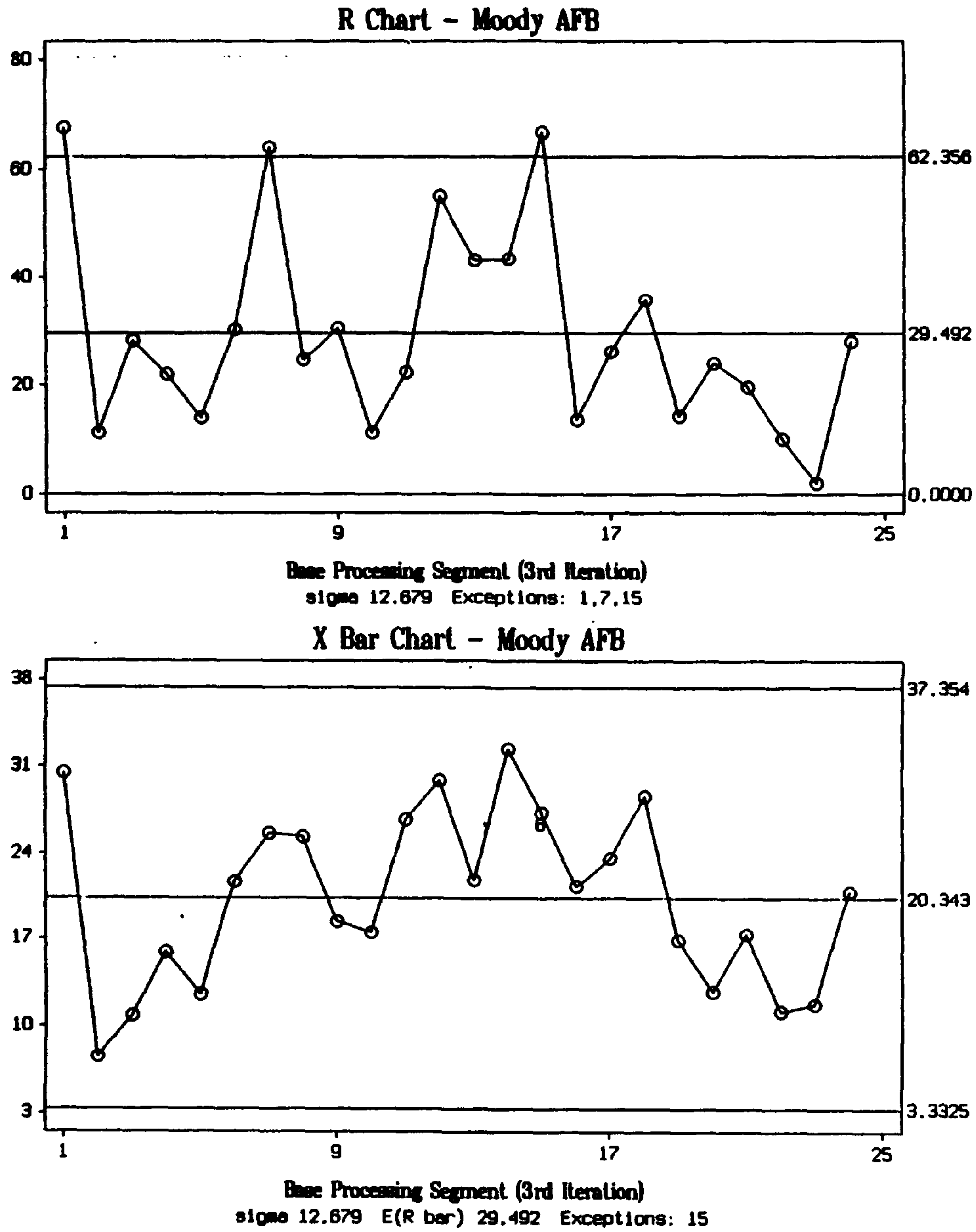
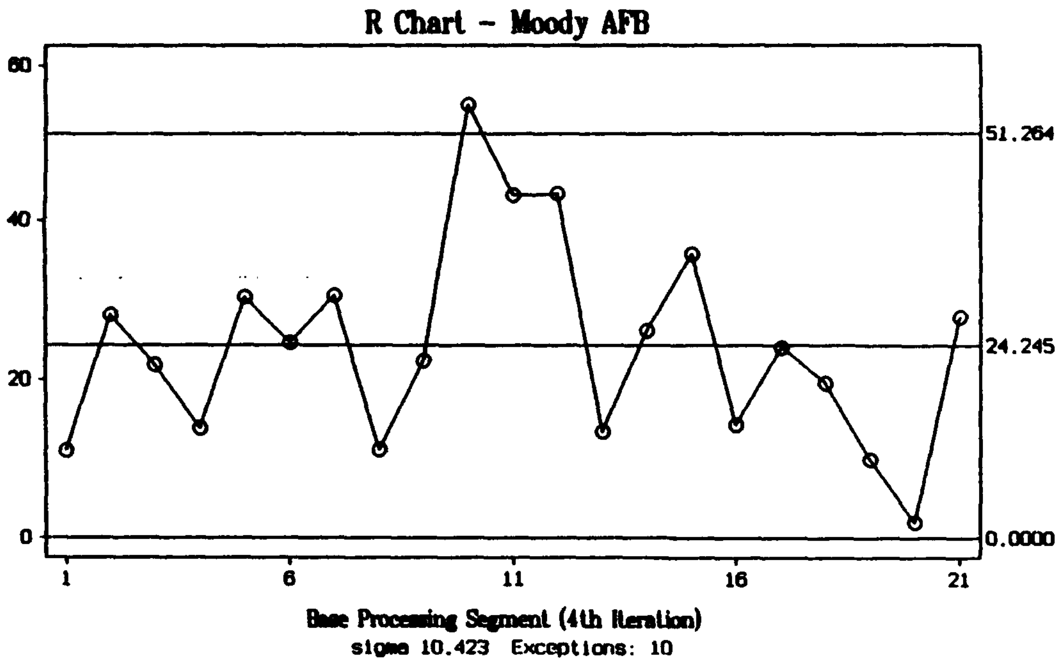


Figure 38. Charts for Moody AFB, 3rd Iteration

With the above Assignable Causes removed, Moody's Base Processing Segment control charts were reproduced. The Moody AFB iteration #4 is shown in Figure 39. Only one out of control condition was identified from this run of the R chart, subgroup 10. Once more we examined information pertaining to this subgroup and found an Assignable Cause of variation. An item in the subgroup was in short supply and the maintenance technicians held the item on a test much longer than normal in an attempt to troubleshoot the asset at base-level. Subgroup 10 was removed from our data base. Up to this point in our analysis, we have focused entirely on the R chart readings. In Chapter Three we discussed how in practice the R chart and the X-bar chart are used together to monitor range and mean simultaneously. For the remaining cases we accomplish just that. The R chart helped us identify the within subgroup variation and expedited our search for Assignable Causes. The X-bar chart identifies between subgroup variation.

Figure 40 is a reconstruction of our charts with subgroup 10 removed. The R chart indicated no out of control conditions, so we changed our focus to the X-bar chart. The X-bar chart from our fifth iteration revealed one out of control condition. Subgroup 11 was above the three-sigma upper control limit and violated test one. Our research indicated that two items in this subgroup were caught in the segment during the three-day Veteran's



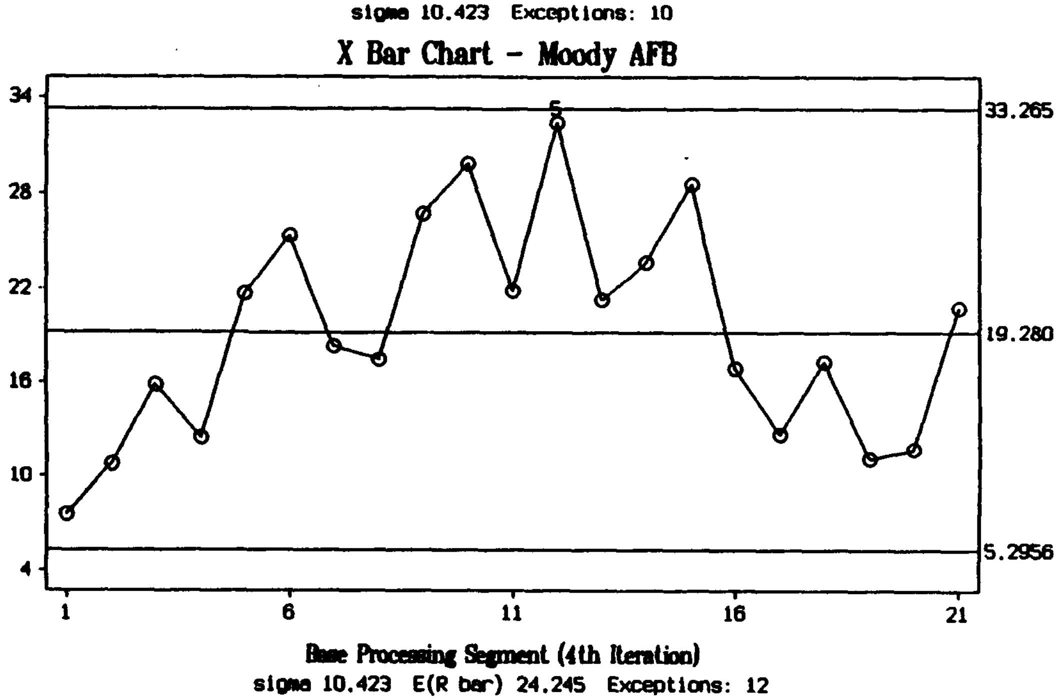
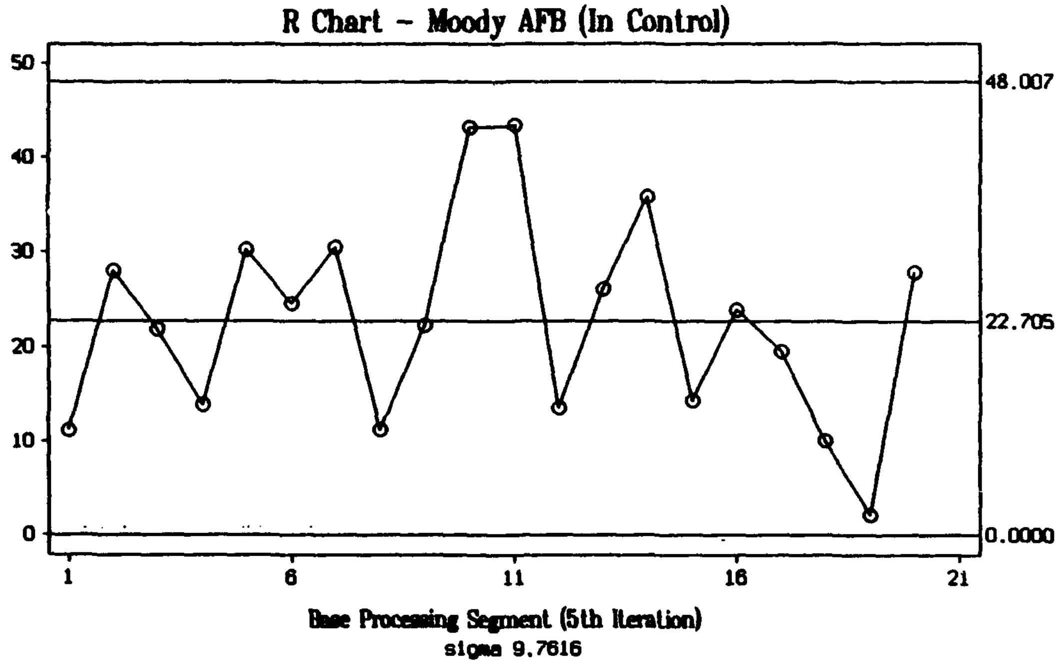


Figure 39. Charts for Moody AFB, 4th Iteration



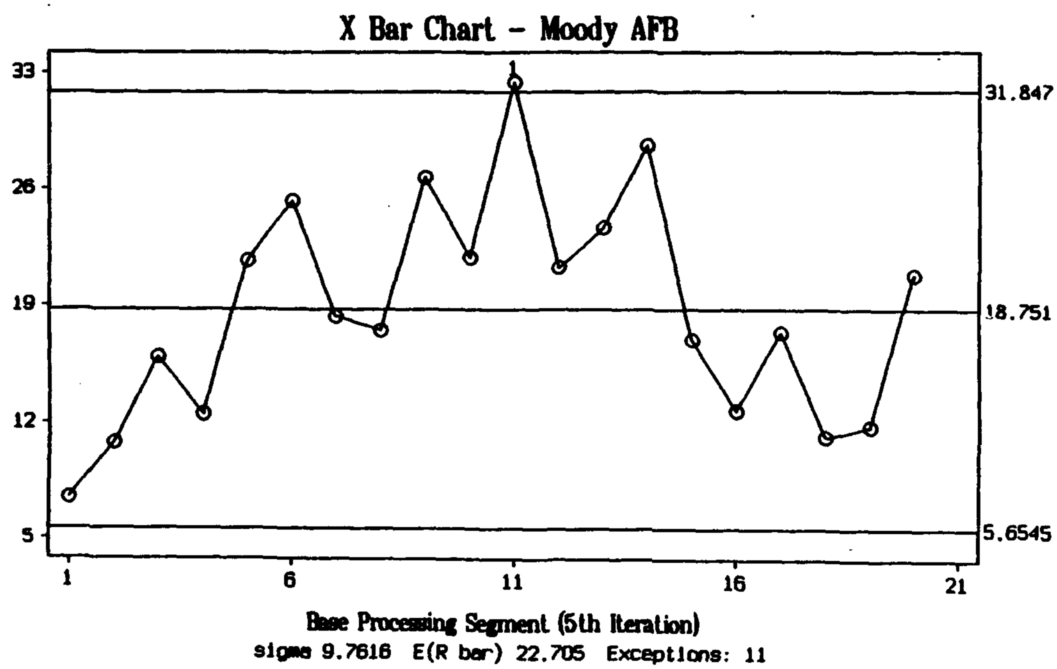


Figure 40. Charts for Moody AFB, 5th Iteration

Day holiday. Because this was not normal and due to an Assignable Cause, the subgroup was removed from our data base.

The final set of control charts for Moody AFB's Base Processing Segment is at Figure 41. No additional out of control conditions were indicated. The center line or mean value for the remaining subgroups was 18.032 hours. With the process stability determined, a capability assessment was possible.

Capability Assessment of the Moody's Base Processing Segment

To accomplish a capability assessment of the Base Processing Segment at Moody AFB, we plotted a histogram using the flow time values associated with the sixth iteration control charts discussed in the previous section. The resulting histogram can be found in Figure 42. We attained process stability by identifying and removing subgroups affected by Assignable Causes of variation. The results were natural process limits that ranged beyond the 24 hour specification limit as set by management. We found natural process flow times that varied from less than 3 hours to greater than 50 hours. There were 26 of the 95 flow times or 27.4 percent over the 24 hour specification limit. Therefore, we determined that the Base Processing Segment at Moody AFB was in the Threshold State--it was in

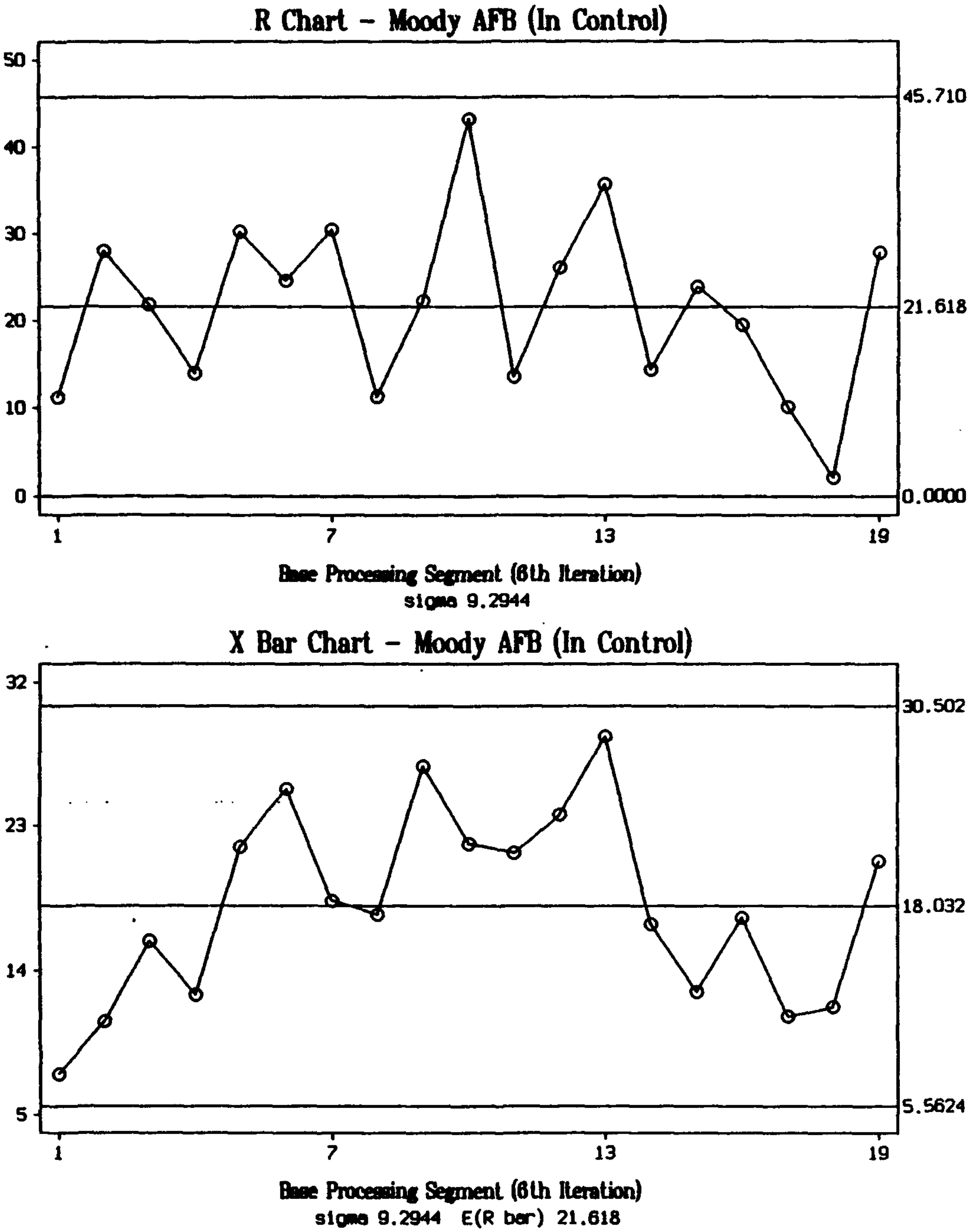


Figure 41. Charts for Moody AFB, 6th Iteration

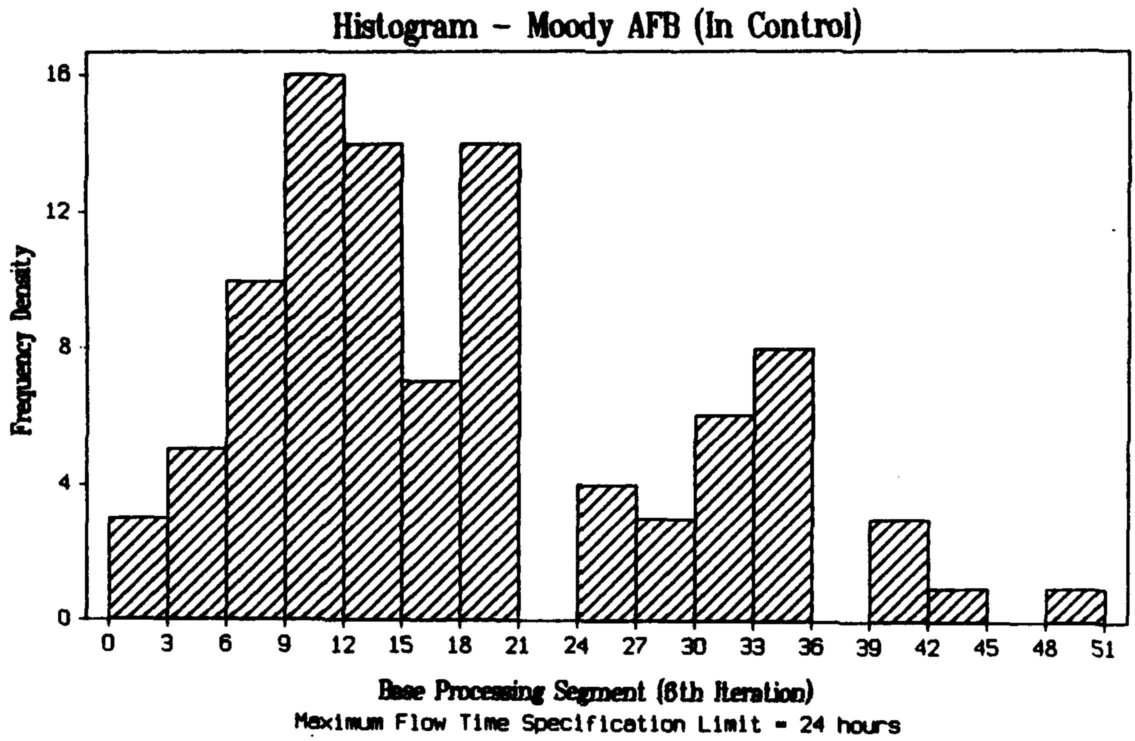


Figure 42. Capability Assessment Histogram, Moody AFB

control, but produced some nonconforming product. The process was stable but not capable.

Intermediate Summary

We answered our first three investigative questions by combining: an in-depth review of current depot-level reparable pipeline literature, direct observation of base-level reparable asset processing actions at Moody AFB, and passive use of control charts. Interviews with personnel involved in managing the Base Processing Segment at Moody AFB provided further insight to CORONET DEUCE II data collection methods and management philosophies. In the next section, we demonstrate how the active use of control charting can be used for continuous process improvements that will reduce retrograde asset flow times.

One-Factor Experiment

Investigative question four was answered through the use of a one-factor experiment. This experiment utilized control charts in the active mode, where changes to the process were made and the effect (state of control) on the process was measured.

To represent the Base Processing Segment, a simulation model was developed to generate flow time data. The simulation model coding is shown in Appendix D. Recall from Chapter 3, a simulation model was used to demonstrate continual improvement because additional data and the capability to experiment with the process at Moody AFB was not possible. The characteristic simulated is the flow of retrograde reparable assets through the Base Processing Segment.

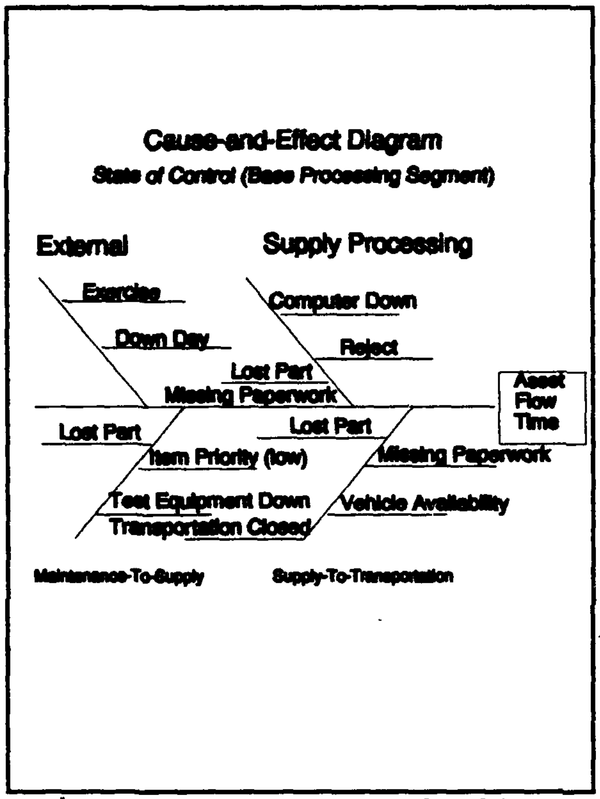


Figure 43. Cause-and-Effect Diagram

Because we are interested in the stability of the process as changes are introduced, it was important to first identify factors that affect the flow of assets through the process. Figure 43 shows a cause-and-effect diagram which identifies factors (Assignable Causes of variation) that affect asset flow times and negatively impact the state of the process. These factors were determined to come from sources external to the process and sources internal to the process (6; 12; 14; 16; 21; 24). Externally, factors that affect asset flow time are Operational Readiness Exercises (OREs) and Wing Down Days. During exercises, normal retrograde asset processing stops and only those parts necessary to maintain aircraft during the exercise are processed. On Wing Down Days, all workcenters associated with the Base Processing closed and assets are not moved through the system until the next scheduled duty day. Both of these factors cause an increase in asset flow time through the system (detailed later).

Internally, or within the Base Processing Segment, factors are present within each subsegment (Maintenance-To-Supply, Supply Processing, and Supply-To-Transportation). In the Maintenance-To-Supply subsegment, factors which affect flow time are lost parts, low processing priority, and broken test equipment. Each of these factors increases asset flow time through this subsegment. Factors identified in the Supply Processing subsegment are computer down time, computer rejects, lost parts, and missing paperwork. An occurrence of any of these events slows or stops asset processing, which increases flow times. In the Supply-To-Transportation subsegment, factors which affect flow time are lost parts, missing paperwork, vehicle availability, and work center unavailability (closed). Each of these factors increases asset flow time through this subsegment. These Assignable Causes of variation will only be introduced during the final phase of the experiment.

Experimental Design. The experiment was conducted in the four phases depicted in Table 3. In the first phase (Tests 1-9), changes to the process were represented by adjusting the minimum, modal, and maximum values in each of the subsegments. The values used in Test 1 came from the final Moody AFB analysis previously presented in this

TABLE 3

EXPERIMENTAL PARAMETERS

PHASE ONE - VARY PROCESS MIN/MODE/MAX

TEST	Maint-To-Supply	Supply Proc	Sup-To-Trans
	SUBSEGMENTS		
1	3.48/16.00/36.47	.02/.08/.37	.08/.3/4.17
2	3.48/16.00/25.00	.02/.08/.37	.08/.3/4.17
3	3.48/16.00/36.47	.02/.08/.17	.08/.3/4.17
4	3.48/16.00/36.47	.02/.08/.37	.08/.3/.54
5	3.48/16.00/25.00	.02/.08/.17	.08/.3/.54
6	3.48/10.00/25.00	.02/.08/.17	.08/.3/.54
7	3.48/16.00/25.00	.02/.05/.17	.08/.3/.54
8	3.48/16.00/25.00	.02/.08/.17	.08/.20/.54
9	3.48/10.00/25.00	.02/.05/.17	.08/.20/.54

PHASE TWO - CHANGE STORAGE CAPACITY (Test #9 is baseline)

	MAINT	SUPPLY	TRANS
10	1	10	10
11	5	2	10
12	5	10	2
13	2	2	2

PHASE THREE - CHANGE ARRIVAL RATE
(Test #9 is baseline)

TEST	EVERY # HOURS
14	10.13
15	6.53
16	3.31
17	2.00
18	1.75

PHASE FOUR INTRODUCE UNCONTROLLED VARIATION
(Test #9 is baseline)

TEST	%ASSIGNABLE
19	0
20	1
21	2
22	3
23	4

chapter. Adjustments to these values in subsequent tests are shown in **bold** type in Table 3. Adjustments in modal values are used to reflect a change in the process aim. Changes to the maximum values are used to show a reduction in Common Causes of variation which indicate a change to the process. Minimum values remain constant.

Phase two of the experiment (Tests 11-13) measures the effect on the process of changes to the capability of each subsegment to process reparable assets. Figure 31 depicts the storage capacity of each of the subsegments. Measuring changes in asset flow time resulting from a change in the processing capacity of each of the subsegments identifies the robustness of the Base Processing Segment and its subsegments.

Phase three (Tests 14-18) also measures the robustness of the Base Processing Segment by introducing different reparable asset arrival rates into the segment and evaluating their effect on the process. The baseline arrival rate, shown in Test 14, is the actual rate of CORONET DEUCE II reparable assets flowing into the Base Processing Segment at Moody AFB, Georgia. Adjustments in this rate were made to show the effect of increasing the number of assets entering the process.

During the final phase (Tests 19 through 23), different levels of Assignable Causes of variation were simulated and their effect on the system measured. Figure 43 shows the Assignable Causes identified that could affect the flow time of reparable assets through the process. Only Assignable Causes of variation associated with the subsegments were used in the experiment. Although we know external causes exist, they were not witnessed during data collection at Moody AFB (previously discussed), nor does data exist that measures their effect on the process. Values used in the simulation model (a simulation model flowchart was shown in Figure 31) to represent asset processing influenced by Assignable Causes of variation were collected at Moody AFB. We were not able to collect values for each individual Assignable Cause, but we were able to identify a processing time associated with all exception processing for each subsegment. In other words, the values used for a subsegment in the model can represent any of the Assignable Causes identified on the cause-and-effect diagram shown in figure 43. Exception (Assignable Cause) processing times are shown in Table 4.

TABLE 4

ASSIGNABLE CAUSE PROCESSING TIME

SUBSEGMENT	MIN/MODE/MAX
Maintenance-To-Supply	3.48/26.00/337.04
Supply Processing	.02/ 1.25/ 3.67
Supply-To-Transportation	.08/ 2.50/ 15.32

Phase One - Vary Process Min/Mode/Max. There were nine tests conducted in this phase of the experiment. In each test, adjustments were made to the asset flow time values (min/mode/max) in one or more subsegments of the Base Processing Segment and the effect on the state of the process and the state of the subprocesses was measured. Control charts were built and analyzed to identify the state of the process resulting from each test. Histograms were constructed to assess the capability of the process when the control charts reflected the process in control. Recall from Chapter 3 that there are four possible States for any process: 1) Ideal State, 2) Threshold State, 3) Brink of Chaos, and 4) State of Chaos. Results for tests one through nine are shown in Table 5.

TABLE 5

TEST RESULTS FOR PHASE ONE

Test	State of the Process
1	Threshold
2	Threshold
3	Threshold
4	Threshold
5	Ideal
6	Ideal
7	Ideal
8	Ideal
9	Ideal

Test 1. In the first test, we used the flow time values (identified in Table 3) from the final Moody AFB analysis. The control charts, X-bar and R, are shown in Figure 44, and a histogram is shown in Figure 45. Using the eight tests for interpreting control charts presented in

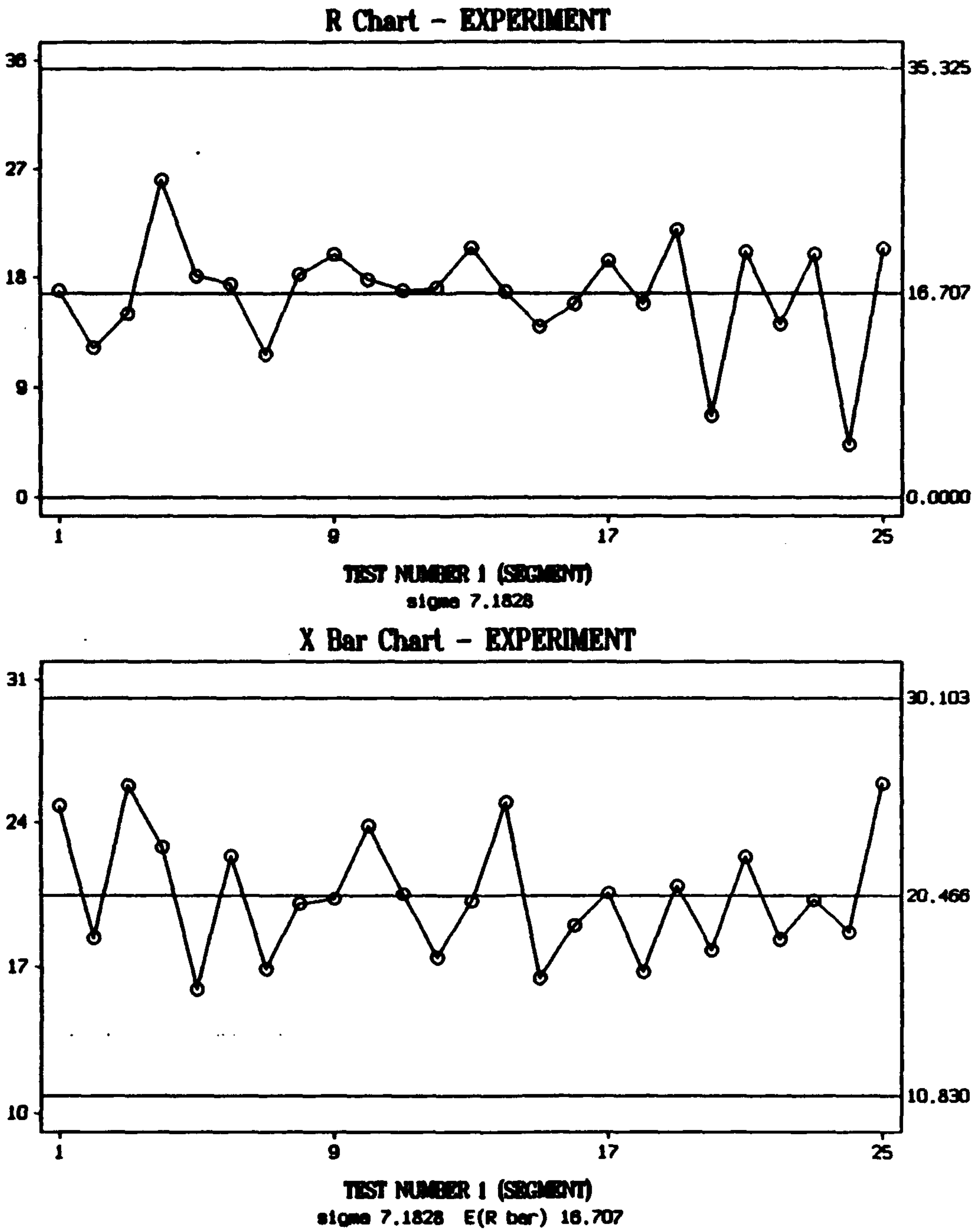


Figure 44. Test 1 Control Charts

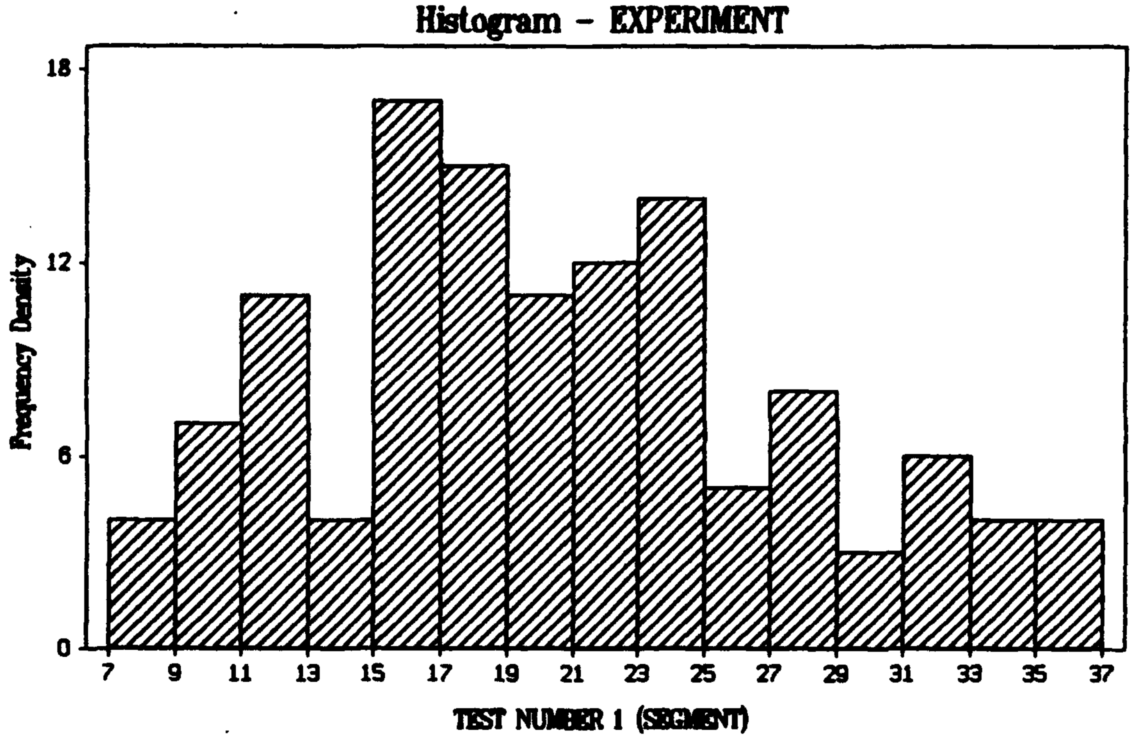


Figure 45. Test 1 Histogram

Chapter 2, both the R and X-bar charts show the process to be in Control. However, the histogram in Figure 45, shows values above the 24 hour specification limit for processing reparable assets at Moody AFB. Therefore, referring back to Figure 13 (the four possibilities for any process) the process is in the Threshold State--in control but producing some nonconforming product. For the subsegments, the control charts shown in Appendix F also reflect the process as in control for each subsegment.

Test 2. In Test 2, the maximum processing time for the Maintenance-To-Supply subsegment was reduced from 36.47 hours to 25 hours and all other times were held constant. This reduction represents a change to the process in this subsegment. All times in the other subsegments were held constant. Control charts for Test 2 are shown in Appendix F. The R and X-bar charts show the process as in control. Note the reduction in the process mean for the segment from 20.466 hours to 16.564 hours. However, enough variability still exists in the process to produce some nonconforming product as indicated in the histogram for this test. Our Test 2 results show the process in the Threshold State.

Test 3. For Test 3, only the maximum processing time for the Supply Processing subsegment was reduced. The maximum time for this subsegment was reduced form .37 hours to .17 hours. Again, as in Test 2, this change represents a change to the process and reduces variation in the process. Analysis of the control charts and histogram for this test (Appendix F) shows the process in control, but still producing some nonconforming product. Test 3 results shows the process in the Threshold State.

Test 4. This test reduces the maximum processing time in the Supply-To-Transportation subsegment from 4.17 hours to .54 hours. Again, as in Tests 2 and 3, this change represents a change to this subsegment process. Analysis of the control charts and histogram for this test (Appendix F) shows the process in control, but still producing some nonconforming product. Our Test 4 results show the process in the Threshold State.

Test 5. In this test, the maximum value for each subsegment was reduced to the level indicated in the previous four tests. This combination of changes was used to reflect improvement in each subsegment of the Base Processing Segment. The control charts for this test, shown in Figure 46, show the process in control on both the R and X-bar charts. Furthermore, the histogram in Figure 47 indicates that the process is producing 100% conforming product. The process displays the characteristics of the Ideal State of Wheeler's paradigm (29:12). That is, the process is stable and the natural process spread is less than the specified tolerance for the product. In the Base Processing Segment, the specified tolerance for product flow times associated with retrograde reparable assets should not

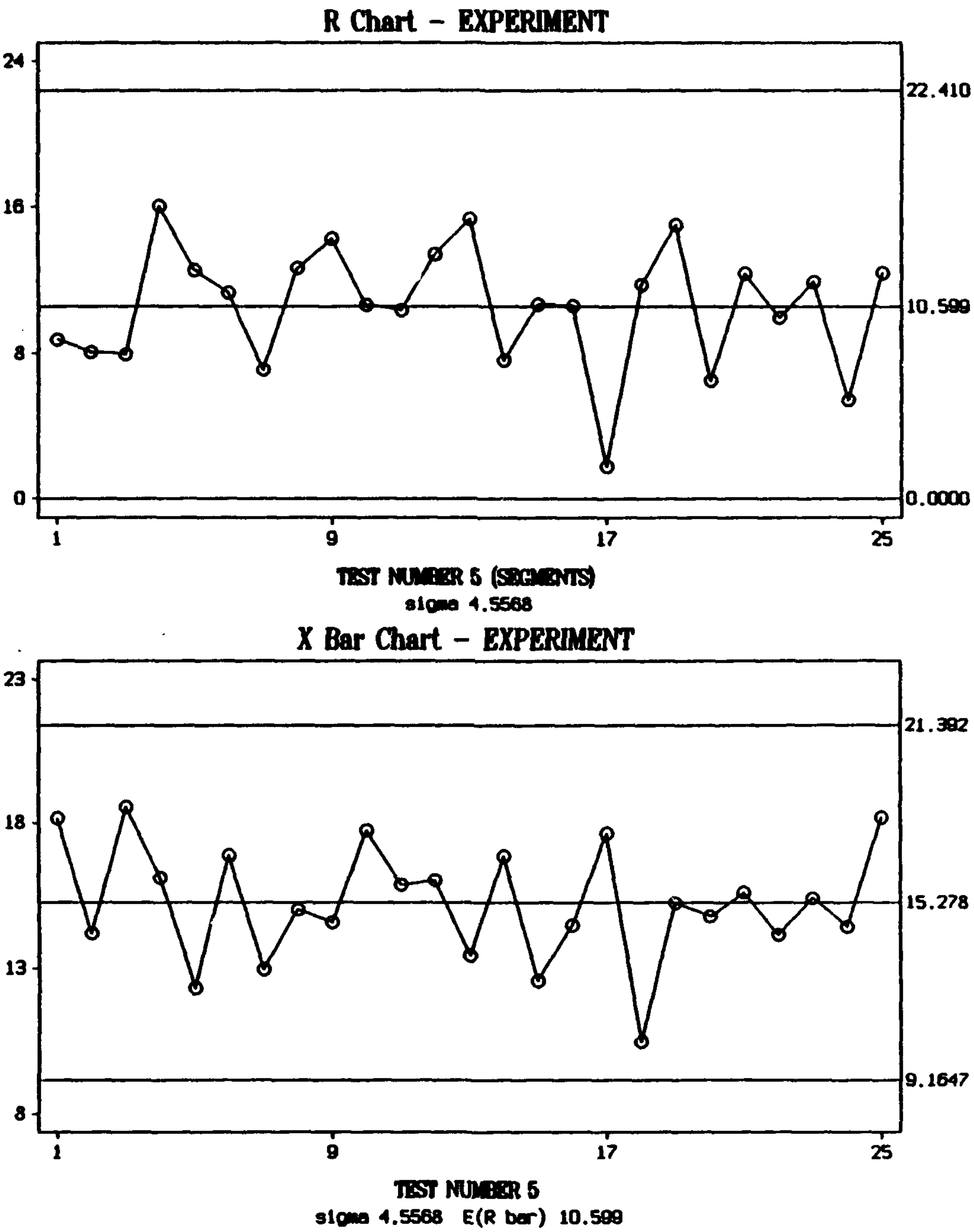


Figure 46. Test 5 Control Charts

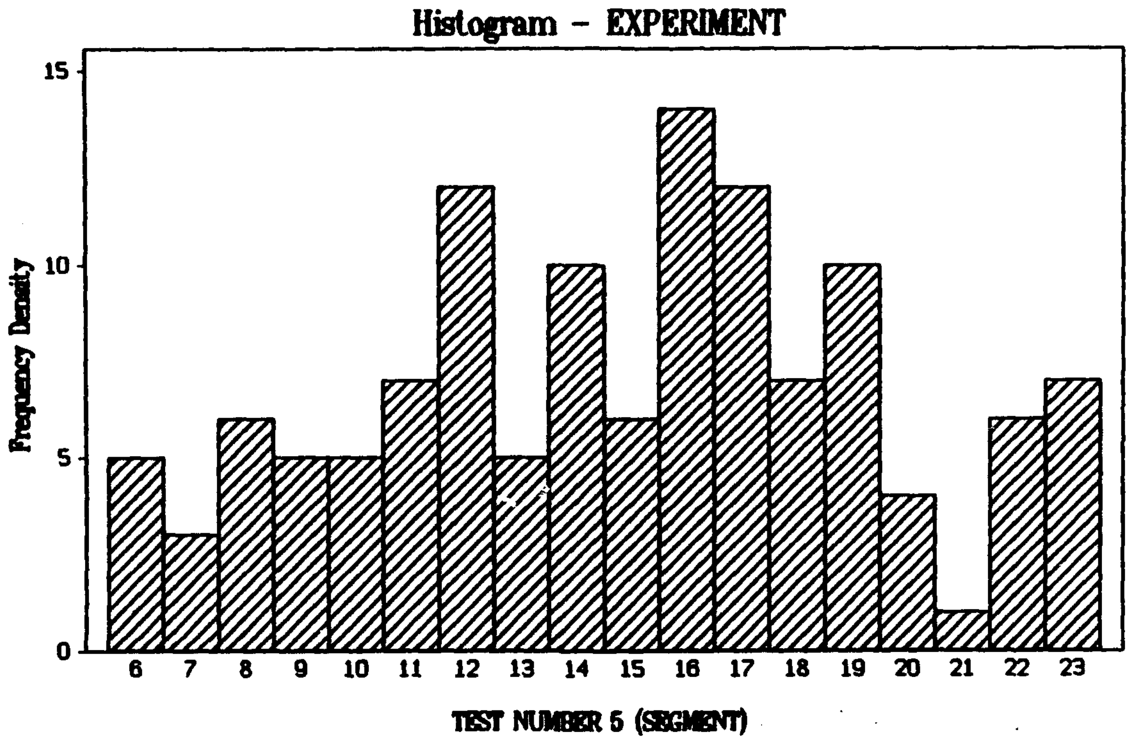


Figure 47. Test 5 Histogram

exceed 24 hours. Figure 47 shows all assets flowed through the segment in less than 24 hours.

<u>Test 6</u>. For the next four tests, we continue experimenting with process improvement by reducing average processing times. Using Test 5 as the baseline for both the minimum and maximum values, changes in the modal value for each subsegment were made and their effects on the stability of the process were measured. In Test 6, the modal value for the Maintenance-To-Supply subsegment was lowered from 16 hours to 10 hours. This change represented a shift in thetarget value for processing retrograde assets through this subsegment. Control charts for this test (Appendix F) show the process in control, with a reduction in the average processing time from 15.278 hours to 13.327 hours. Additionally, the histogram reflects 100% conforming product. The process is in the Ideal State.

<u>Test 7</u>. In this test, the mode for the Supply Processing subsegment is lowered from .08 hours to .05 hours. All other subsegment times revert back to their baseline values from Test 5. As in Test 6, the purpose of this test is to reflect a shift in the processing time target value. The control charts and histogram for this test are found in Appendix F. Both the R and X-bar charts indicate the process is in control. The histogram reflects that all assets flowed through the system in under 24 hours. Therefore, the process is in the Ideal State.

Test 8. The modal value for the Supply-To-Transportation subsegment was lowered for this test, and all other subsegment times reverting back to the Test 5 baseline values. Again, as in Tests 6 and 7, the purpose is to reflect a shift in the processing time target value. The R and X-bar charts (Appendix F) show the process in control. Additionally, the histogram (Appendix F) indicates the process is producing 100% conforming product. The process is in the Ideal State.

Test 9. For this test, the modal value for each subsegment was set to the lowest value used in Tests 6 through 8. This combination of changes was used to reflect improvement in each subsegment of the Base Processing Segment. Figure 48 shows the control charts for this test, and Figure 49 is the histogram. Both control charts (Figure 47) show the process to be in control. The histogram in Figure 49 indicates all assets flowed through the segment in less than 24 hours. The process is in the Ideal State. Control charts are also shown in Appendix F for the three Subsegments. In each subsegment, the R and X-bar control charts show the subsegments in control.

As we progressed through the changes to the process during Phase One of the experiment, an interesting result surfaced. The only significant improvements to retrograde reparable asset flow time occurred as a result of

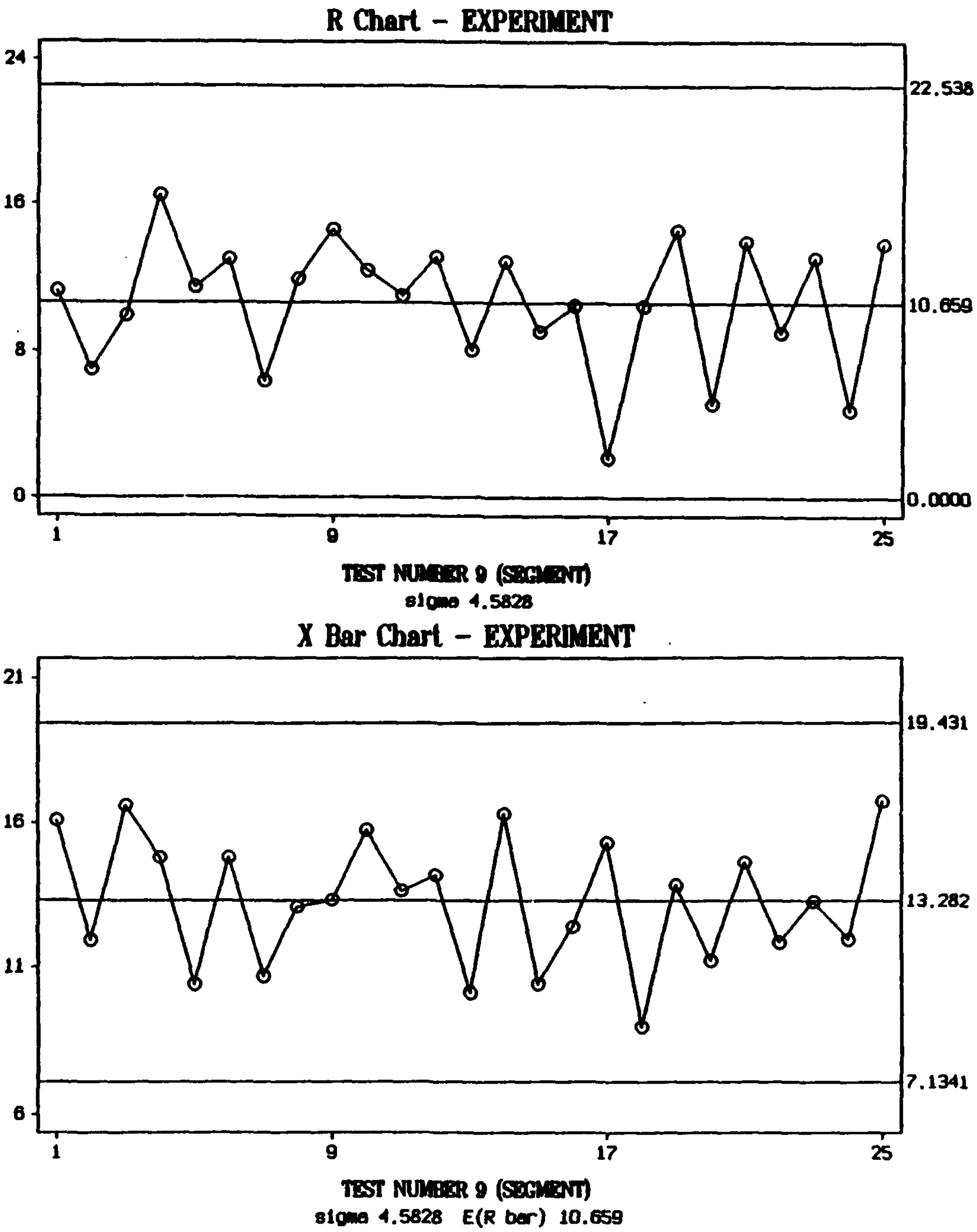


Figure 48. Test 9 Control Charts

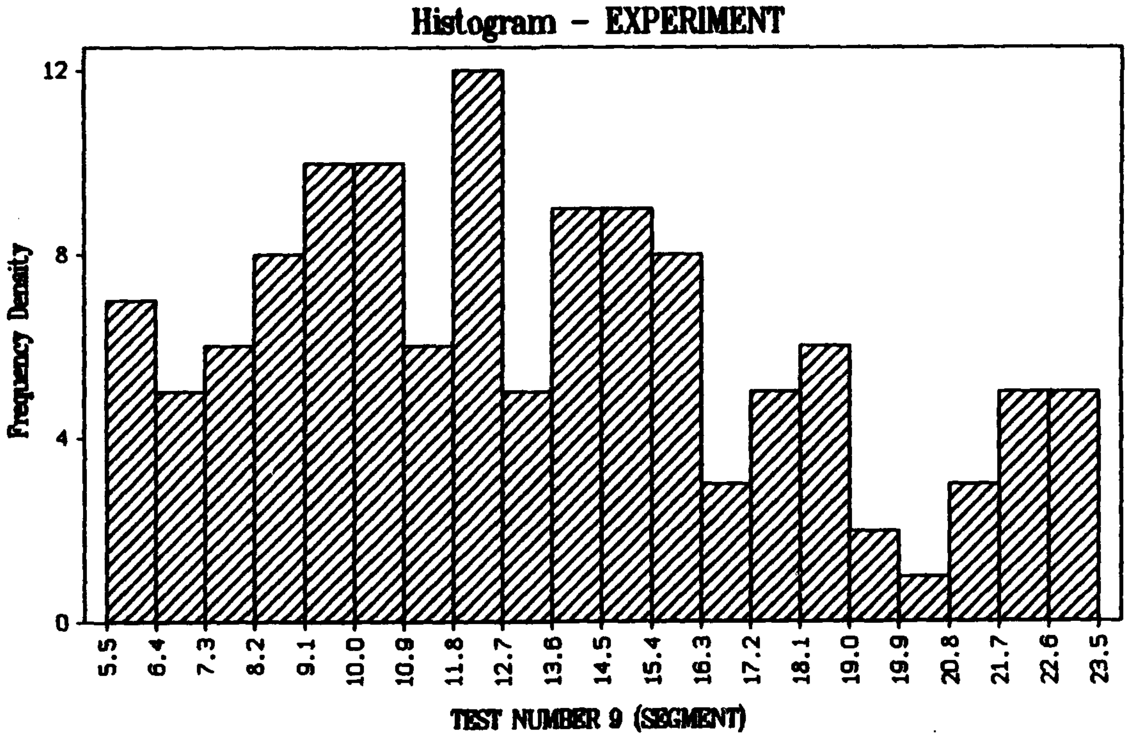


Figure 49. Test 9 Histogram

changes in the Maintenance-To-Supply subsegment. This is explained by virtue of the fact that while assets are in the Base Processing Segment, they spend over 91 percent of the time transversing the Maintenance-To-Supply subsegment. Table 6 contains the asset mean flow time from the X-bar chart from each of the ..ine tests from Phase One. Note that each time a significant reduction is made in asset mean flow time it involved a change to the Maintenance-To-Supply subsegment.

TABLE 6

PROCESS MEAN TIMES FOR PHASE ONE

Test	Process Mean
1	20.466
2	16.564
3	20.391
4	19.256
5	15.278
6	13.327
7	15.268
8	15.243
9	13.282

Phase Two - Change Storage Capacity. The purpose of this phase of the experiment is to test the robustness of the process. In this phase, changes to the processing capacity of each subsegment were made and the effect measured. Again, control charts were built and analyzed to identify the state of the process resulting from each test. Histograms were constructed to access the capability of the process when the control charts reflected the process in control. A summary for these tests (10-13) is shown in Table 7.

TABLE 7

STORAGE CAPACITY TEST RESULTS

Test	State of the Process
10	Chaos
11	Ideal
12	Ideal
13	Threshold

Test 10. Recall from Figure 31 that the Maintenance-To-Supply subsegment can process up to five CORONET DEUCE II assets at one time. For this test, we reduced the number from five to one. This reduction was made to simulate the normal after-hours manning in the Flight Service Center. The processing capacity for the other two subsegments remain at ten. Control charts (Figure 50) for this test indicate that the process is out of control. On the X-bar chart, there are 17 out of control points. Fifteen points are beyond 3-sigma control limits (indicated by a 1 on the chart), and two points fail test 5: two out of three points in a row in zone A or beyond on one side of the center line. A histogram was not run for this test because the process was not stable. Control charts for the subsegments (Appendix F) reveal the Maintenance-To-Supply subsegment out of control for the exact reasons at the segment, and the other subsegments were in control.

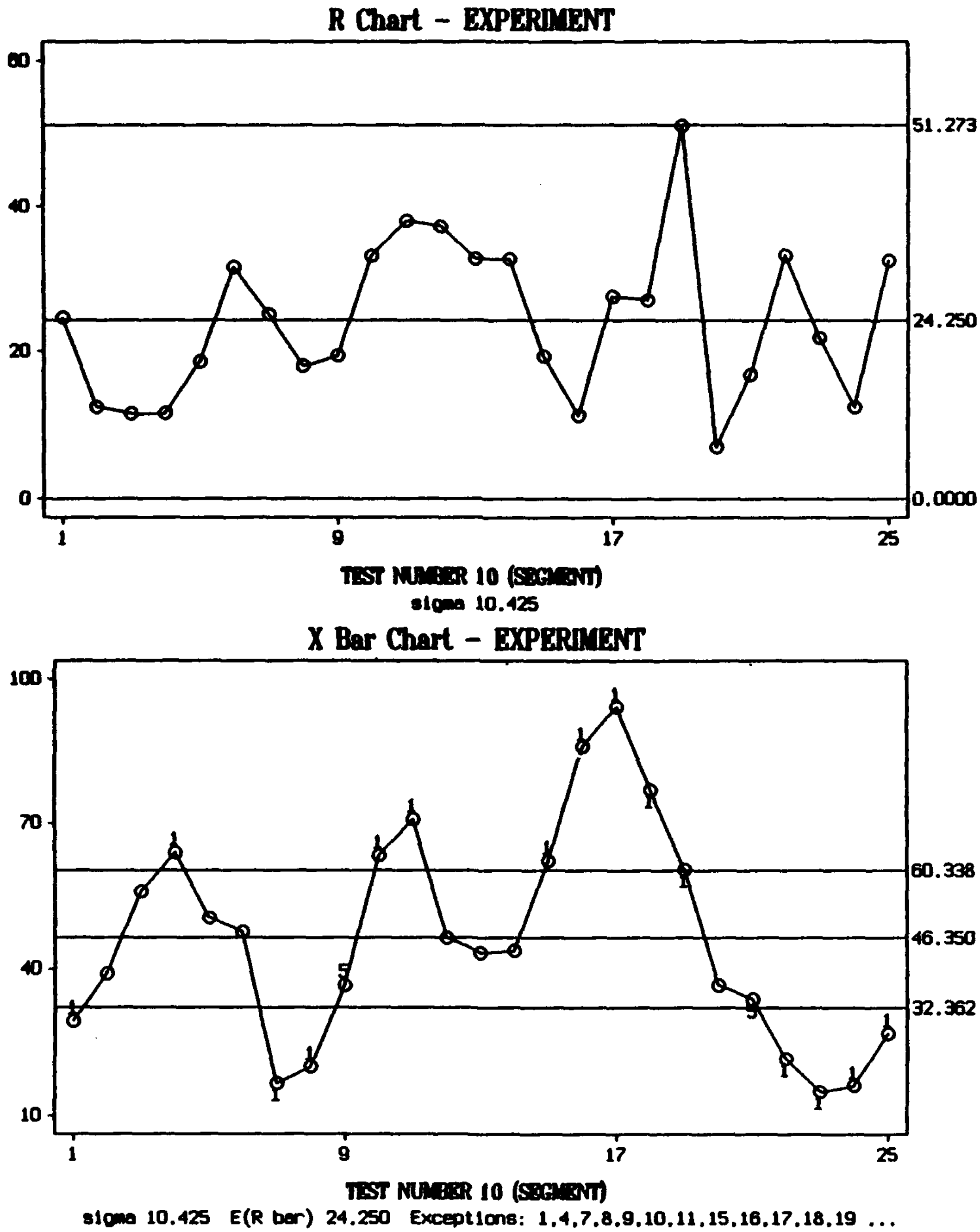


Figure 50. Test 10 Control Charts

Test 11. For this test, the Supply Processing subsegment processing capacity was reduced from ten to two, with the other subsegments at normal capacity. This change had no impact on the stability of the process as indicated by the control charts in Appendix F. Note the robustness of the Supply Processing subsegment, as it remains in control even with a drastic reduction in processing capability. The Base Processing Segment is in the Ideal State.

Test 12. For this test, the Supply-To-Transportation subsegment processing capacity was reduced from ten to two, with the other subsegments at normal capacity. Like Test 11, this change had no impact on the stability of the process. The control charts for this test are found in Appendix F. The Supply-To-Transportation subsegment is also very robust as it remains in control with the reduced capability. The Segment is in the Ideal State.

Test 13. Processing capacity for all subsegments was reduced to two for this test. The control charts in Figure 51 show the process in control. However, the histogram in Figure 52 reveals the process is now producing some nonconforming product. The process is in the Threshold State.

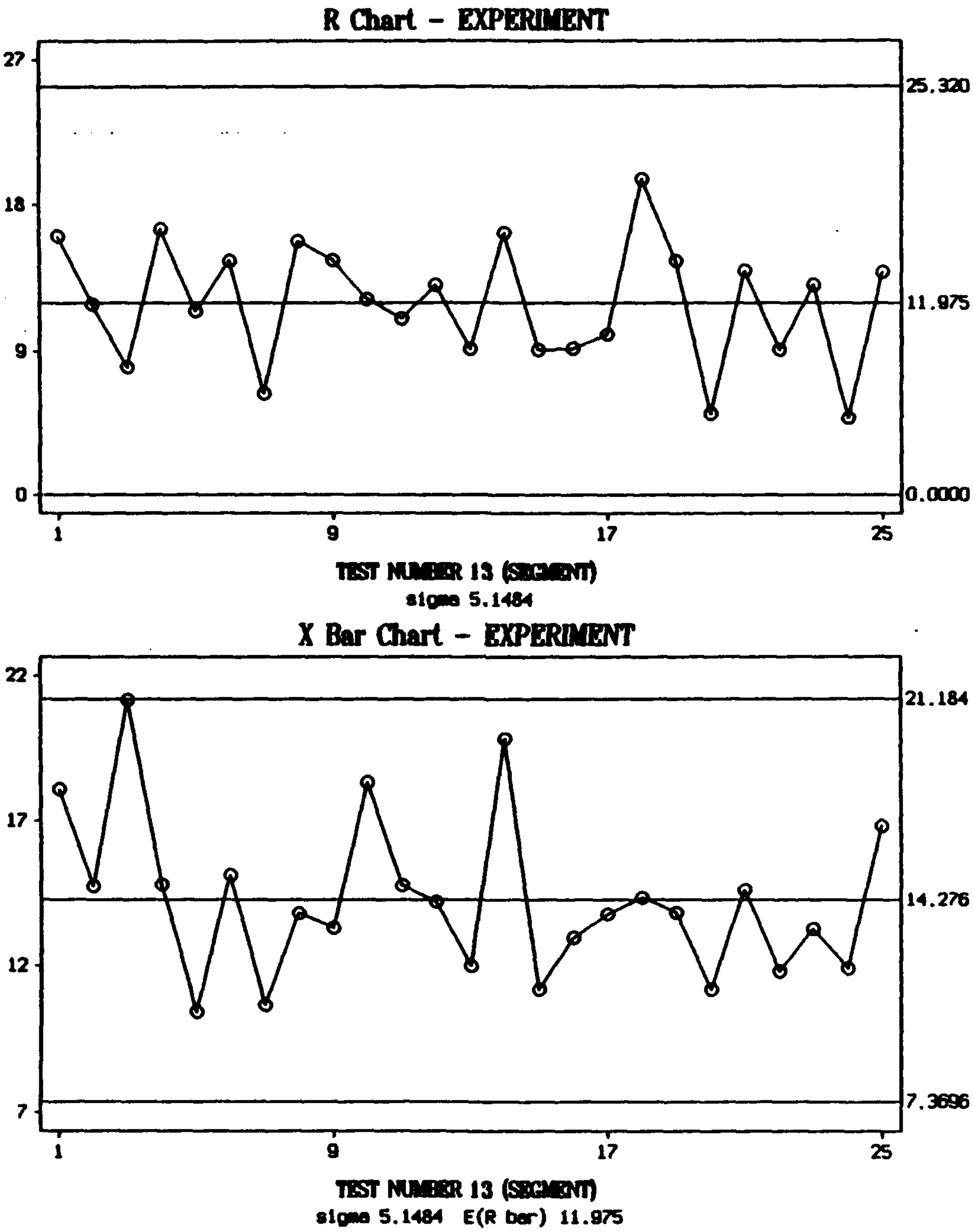


Figure 51. Test 13 Control Charts

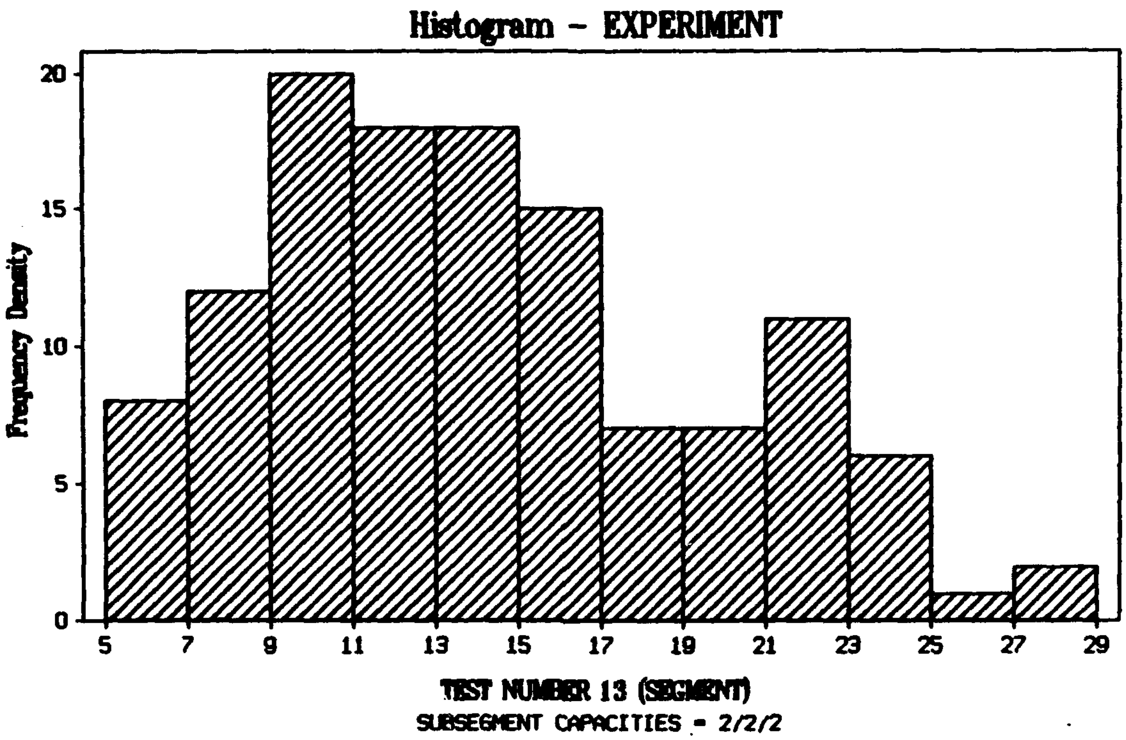


Figure 52. Test 13 Histogram

Phase Three - Change Arrival Rate. In this phase, different reparable asset arrival rates were introduced into the Base Processing Segment and their effect evaluated. Subsegment processing times are from Test 9. Table 8 summarizes test results for this phase of the experiment.

TABLE 8

ARRIVAL RATE TEST RESULTS

Test	State of the Process
14	Ideal
15	Ideal
16	Chaos
17	Chaos
18	Chaos

Test 14. The actual CORONET DEUCE II reparable asset arrival rate of one asset every 10.13 hours was used for this test. This arrival rate defines how often a reparable asset enters the Base Processing Segment. Figure 53 contains the control charts for this test and Figure 54 is the histogram of the data. Both the R and X-bar charts show the process in control. The histogram (Figure 54) reflects all assets are progressing through the segment under the 24 hour specified time standard. Therefore, the segment is in the Ideal State.

Test 15. For this test, the arrival rate was reduced to an asset arrival every 6.53 hours. This change resulted in no change to the state of the process. The control charts and histogram are in Appendix F.

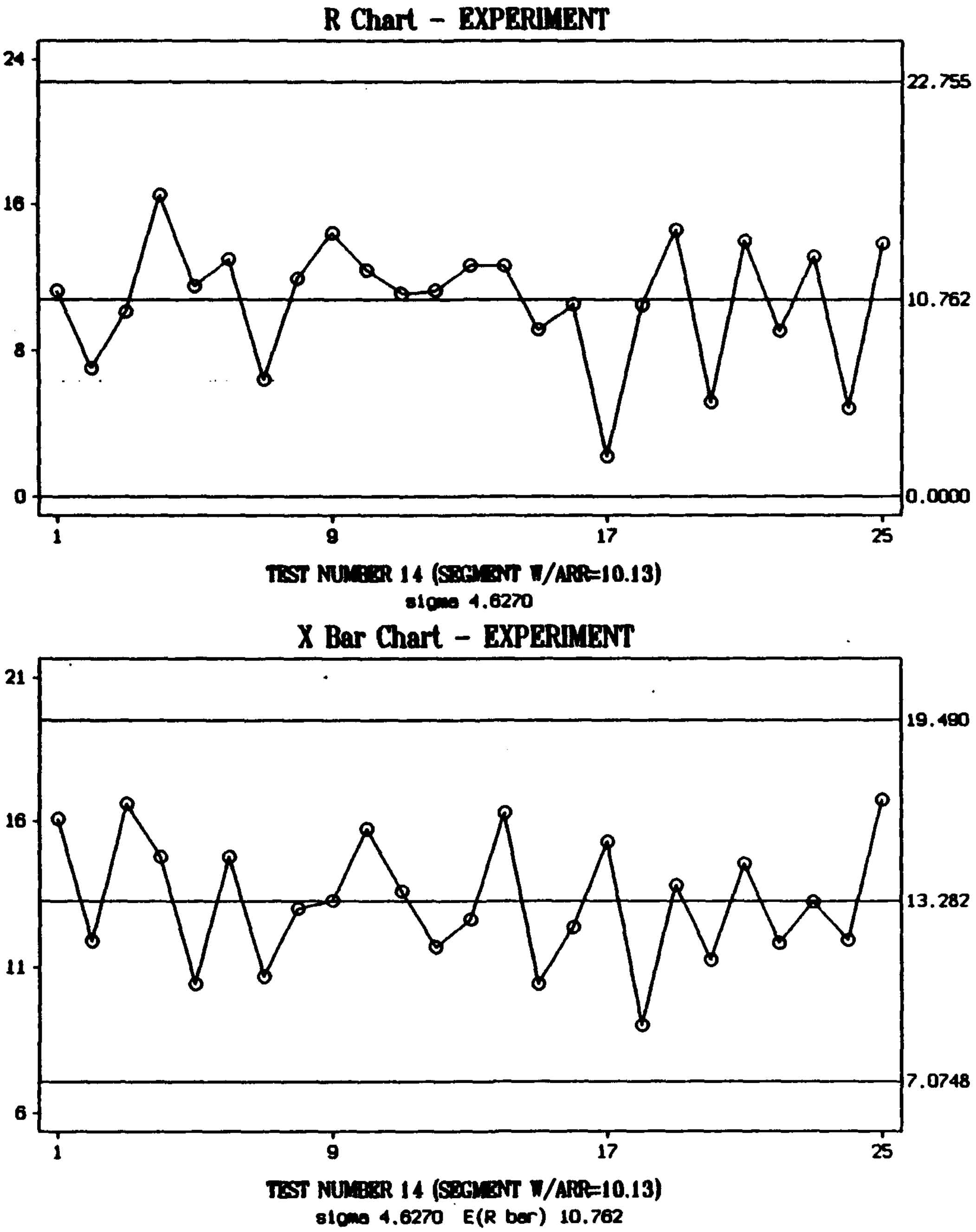


Figure 53. Test 14 Control Charts

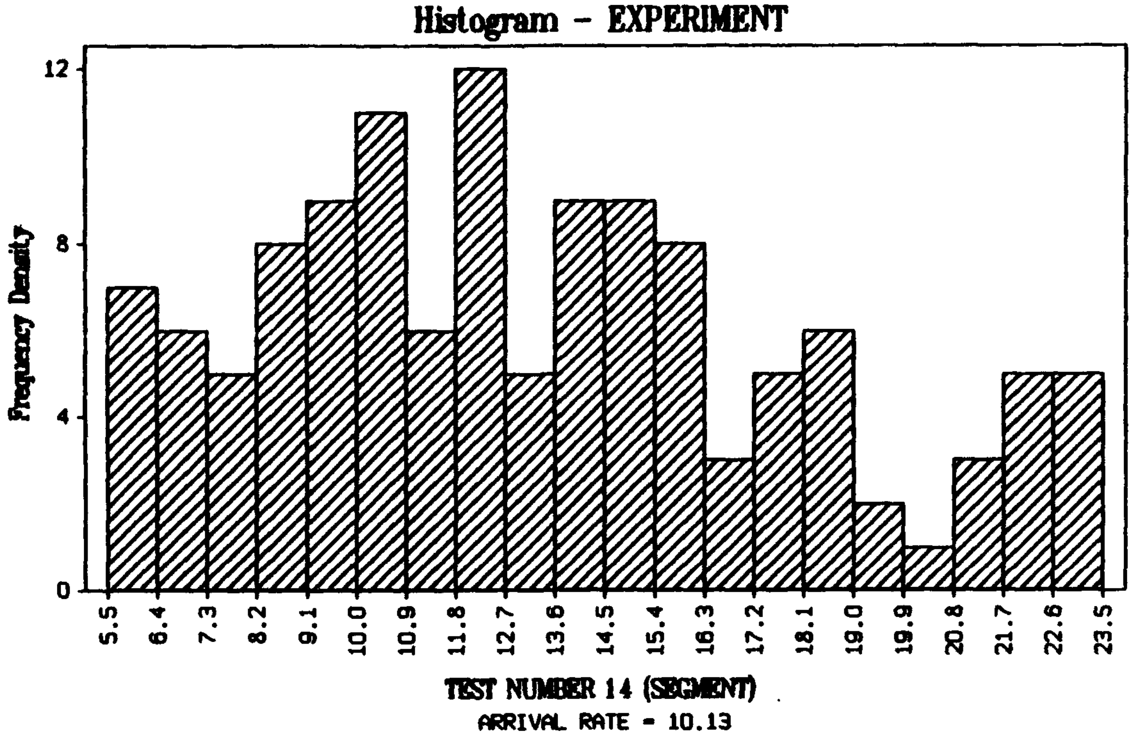
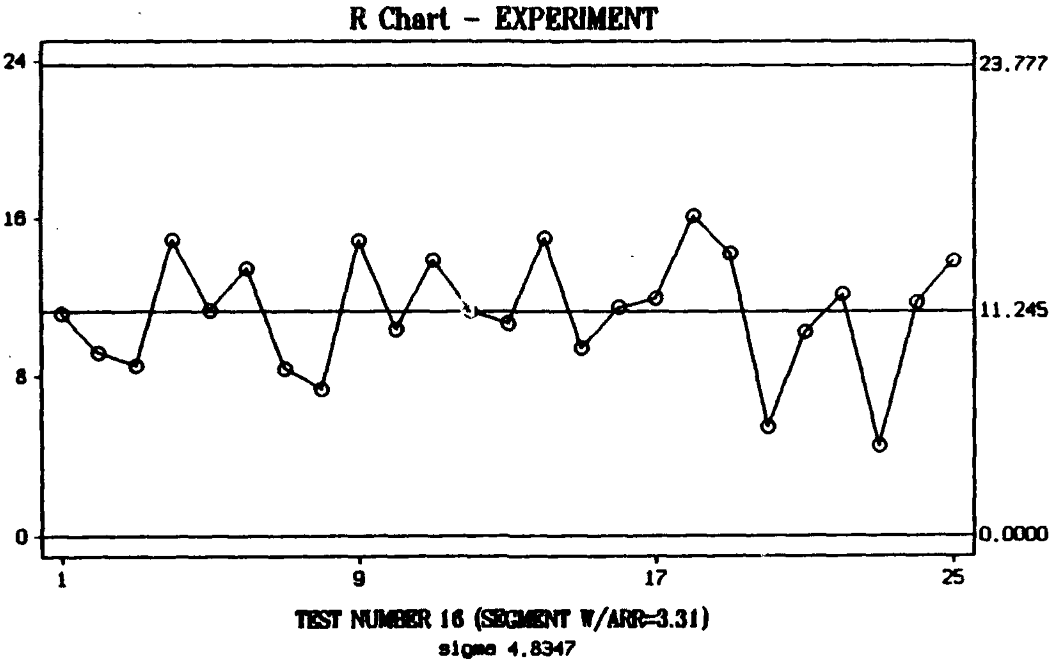


Figure 54. Test 14 Histogram

Test 16. To further stress the process, the arrival rate was again reduced for this test. An asset arrival rate of every 3.31 hours produced a change in the state of the process. As you see in the control charts in Figure 55, the process is out of control because of data point 16 and 17. Point 16 fails Test #1 (Figure 21) and point 17 fails Test #5 (Figure 25). The process is now in the State of Chaos.

Tests 17 and 18. Further reductions in the asset arrival rates were made for these two tests. The control charts in Appendix F show that as the arrival rate is further decreased, the average asset flow time through the segment increases. In Test 17, the arrival rate is an asset every two hours. The asset flow time for Test 17 is 45.09 hours. In Test 18, the arrival rate is an asset every 1.75 hours. The asset flow time for Test 18 is 60.72 hours. In both tests, the process is out of control and in the State of Chaos.

Phase Four - Introduce Uncontrolled Variation. For the next five tests, Assignable Causes of variation were introduced into the simulation model and the effect measured. The purpose of these tests is to show that Assignable Causes will and can occur in any process (29:157), and when they do the state of the process will be affected. In the Base Processing Segment, Assignable Causes of variation cause parts to be delayed in the process. This delay amounts to increased processing time for the assets



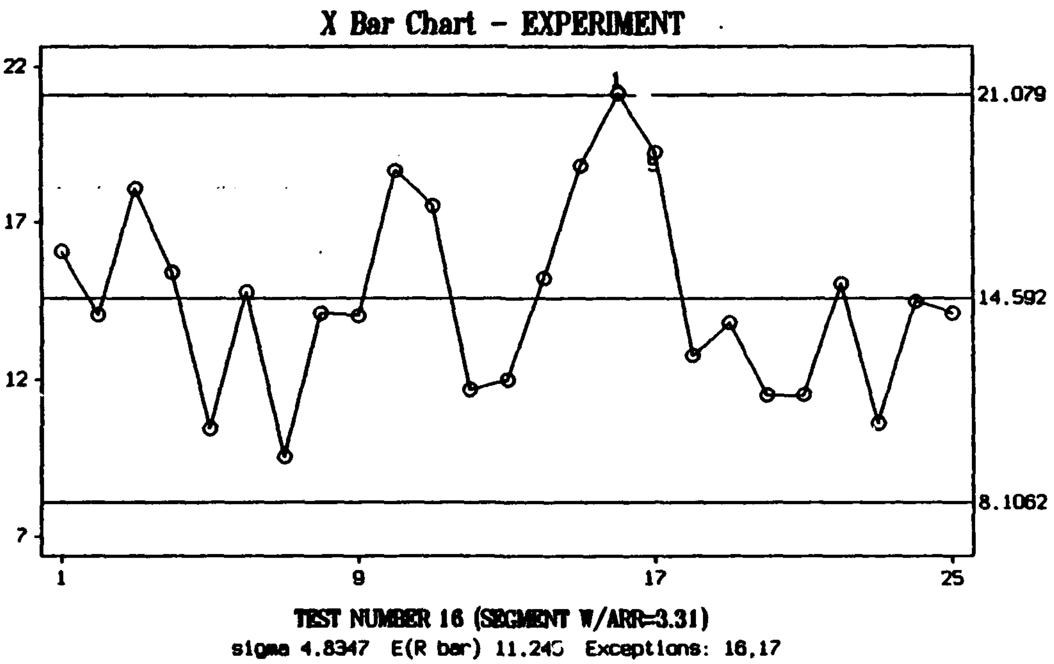


Figure 55. Test 16 Control Charts

involved. Flow times associated with these Assignable Causes were identified in Table 3. Results for Tests 19 through 23 are shown in Table 9.

TABLE 9

ASSIGNABLE CAUSE TEST RESULTS

Test	State of the Process
19	Ideal
20	Ideal
21	Chaos
22	Chaos
23	Chaos

Test 19. In this test no Assignable Causes of variation are introduced into the process. Since we used Test 9 as the base line, we expect the process to be in the Ideal State. The control charts and histogram for this Test, shown in Appendix F, confirm the process is in the Ideal State.

Test 20. In this test, one percent of the reparable assets flowing through the Base Processing Segment were influenced by Assignable Causes of variation. The control charts in Figure 56 show that the process is in control, and the histogram at Figure 57 reflects 100 percent conforming product. We conclude that the process is in the Ideal State. However, note in Figure 58 and Figure 59 that the Supply Processing and Supply-To-Transportation subsegments are both out of control. Due to randomness,

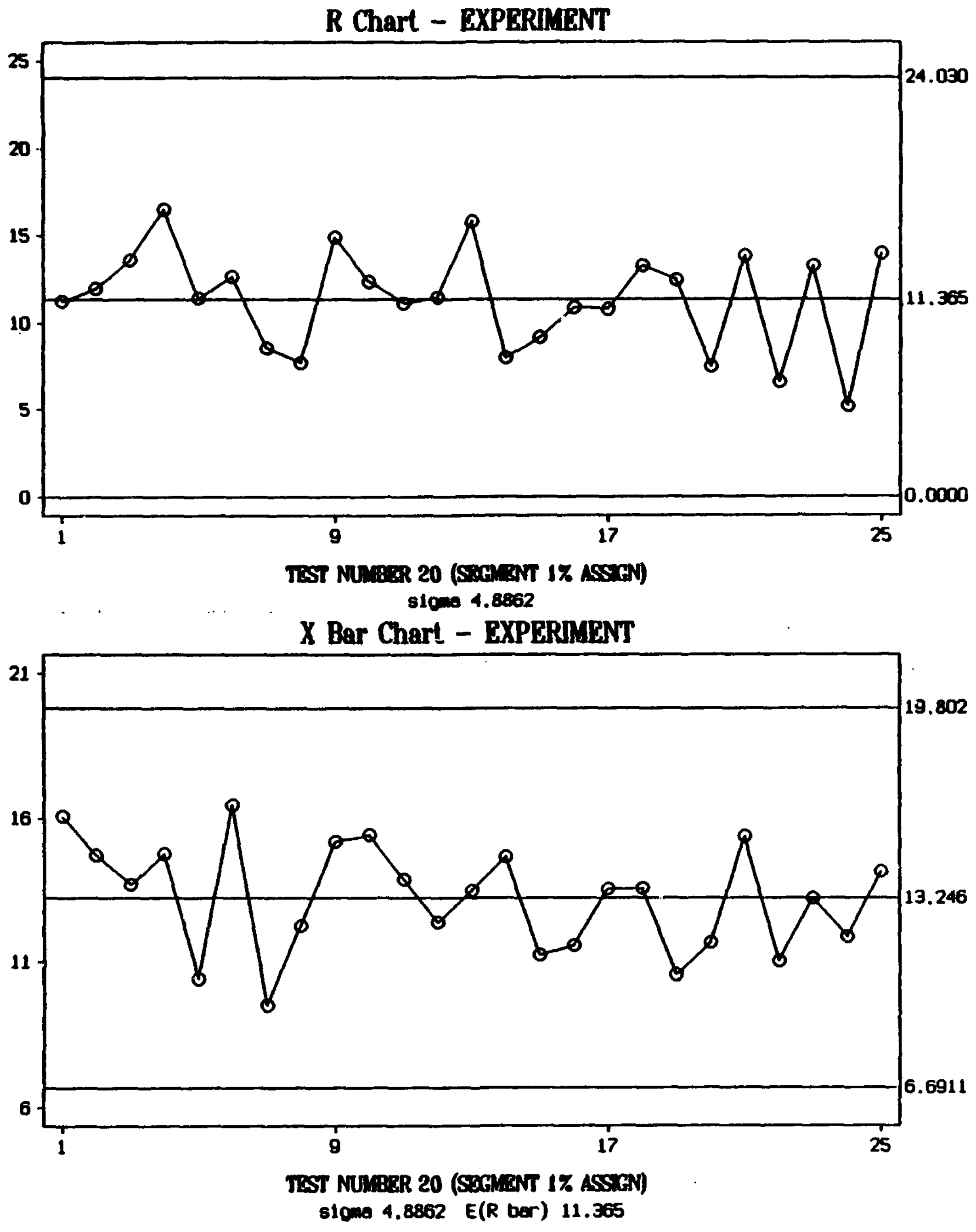


Figure 56. Test 20 Control Charts (Segment)

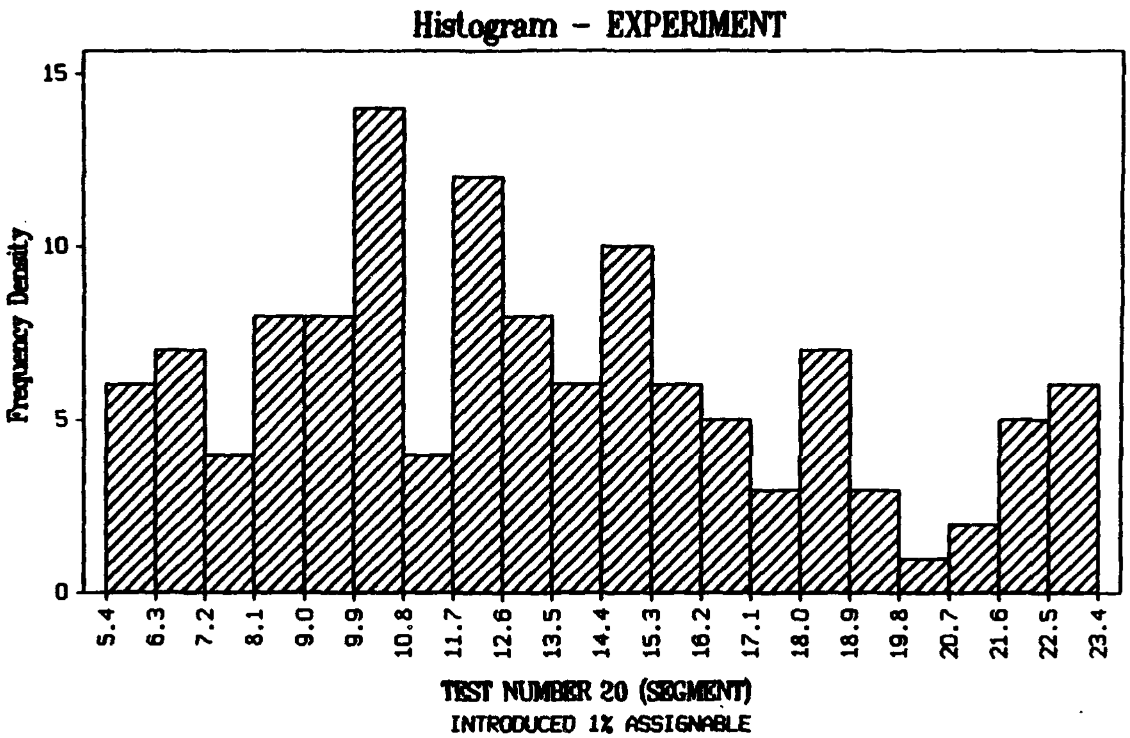


Figure 57. Test 20 Histogram

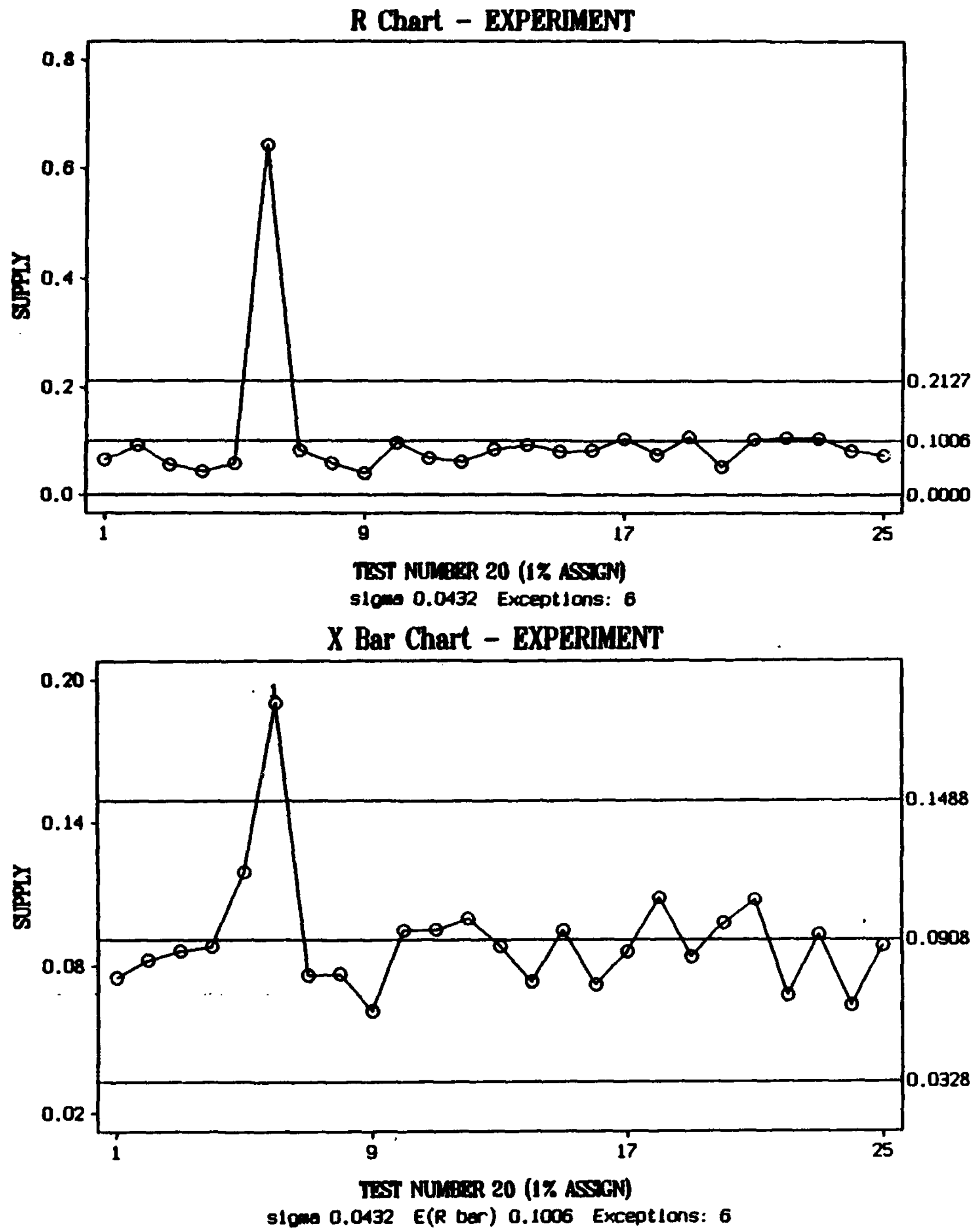


Figure 58. Test 20 Control Charts (Supply Processing Subsegment)

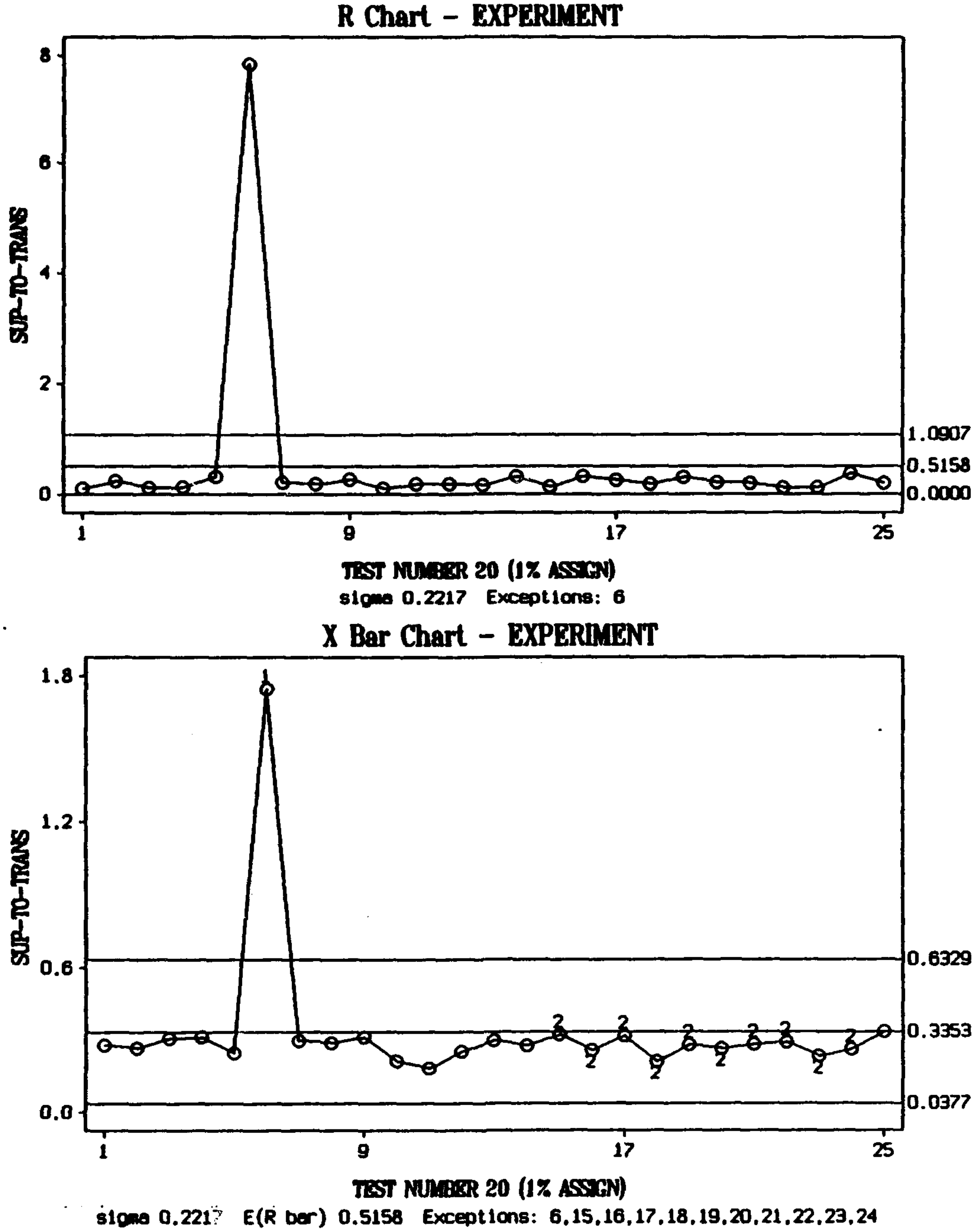


Figure 59. Test 20 Control Charts (Supply-To-Transportation Subsegment)

both of these subsegments were impacted by Assignable Causes of variation and the Maintenance-To-Supply subsegment was not affected.

Test 21. The percentage of Assignable variation was increased in this test from one to two percent. The result of this increase is an out of control process in the State of Chaos. The control charts for this test are at Figure 60. Analysis of the charts shows data points outside the 3-sigma control limits. Analysis of the control charts for the subsegments (Appendix F) reveals all subsegments out of control.

Tests 22 and 23. In these tests, the percentage of Assignable Causes of variation is increased to three and four percent respectively. Control charts are in Appendix F for these tests. Analysis of the charts reveal that the Base Processing Segment and the subsegments are out of control for points outside 3-sigma control limits.

One-Factor Experiment Summary

In our one-factor experiment, we were able to effectively demonstrate the use of active control charting for continuous process improvement. Phase one of the experiment was designed to show how changes in process variation impact the process. By eliminating Common Causes of variation, we were able to move the process from the Threshold to the Ideal State and reduce the process mean

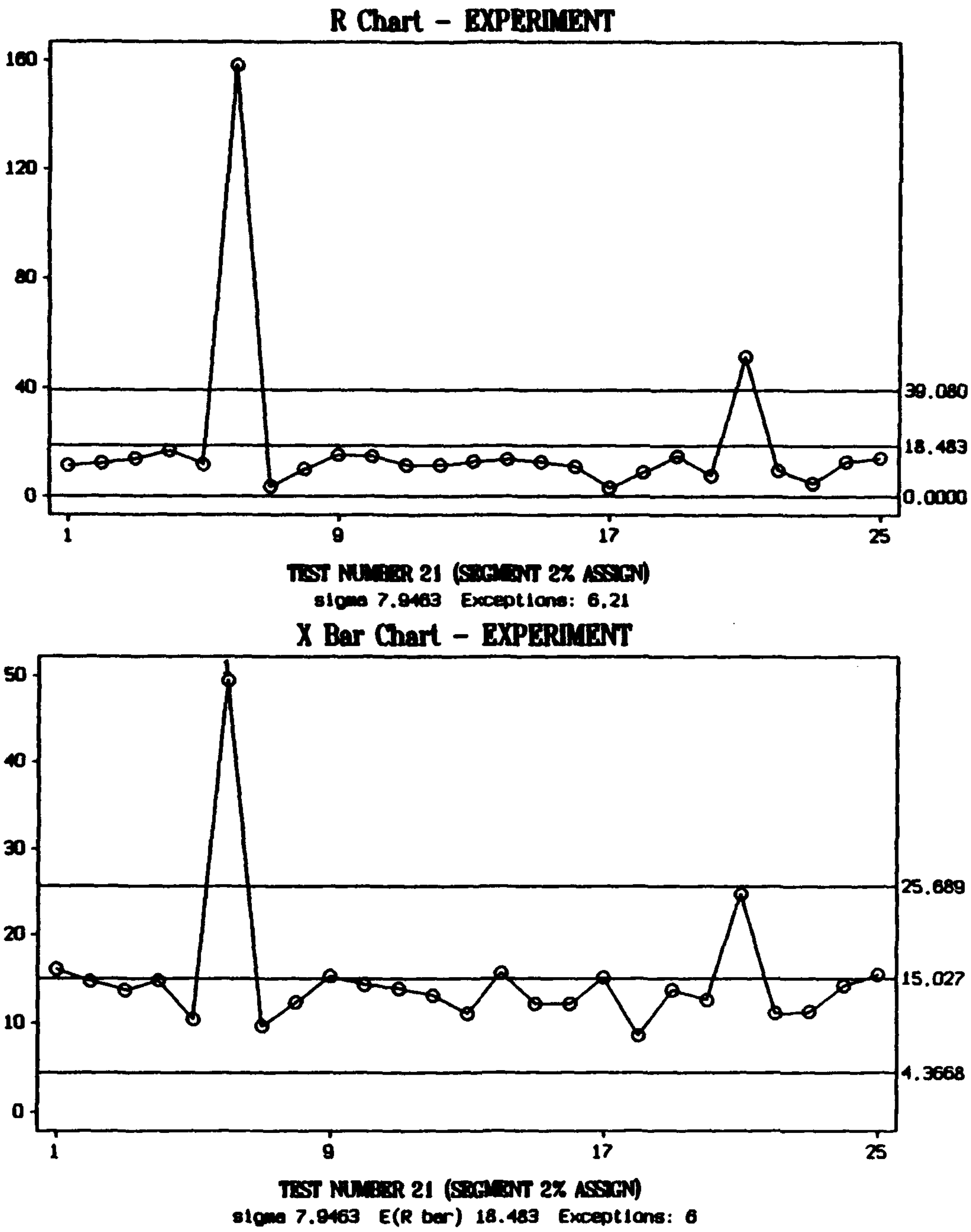


Figure 60. Test 21 Control Charts

time from 20.466 hours to 13.282 hours. In phase two, we tested the robustness of the process by changing the capacity of each subsegment and measuring the effect. We discovered that the process is sensitive to change only in the Maintenance-To-Supply subsegment. A capacity below three moves this subsegment into the State of Chaos.

Phase three of the experiment was designed to measure the effect of different reparable asset arrival rates on the process. The system remains robust and in the Ideal State until arrival rates reach one asset every 3.31 hours. The purpose of the final phase was to introduce Assignable Causes of variation into the simulation model and measure the effect. The results showed that the Supply Processing and Supply-To-Transportation subsegments can be out of control and not necessarily affect the state of the process of the overall segment. However, any introduction of Assignable Causes of variation into the Maintenance-To-Supply subsegment causes the segment to move to the State of Chaos. We attribute this to the fact that 91 percent of the time assets are in the Base Processing Segment, they are in the Maintenance-To-Supply subsegment.

Chapter Summary

This chapter answered the investigative questions presented in this thesis. The Base Processing Segment of the depot-level reparable pipeline was dissected into three subsegments: Maintenance-To-Supply, Supply Processing, and

Supply-To-Transportation. The current data collection system was studied and management's use of the data to make decisions was detailed. Control charts were used in the passive mode to determine the state of control of the Base Processing Segment at Moody AFB, Georgia. Finally, control charts were used in the active mode to demonstrate where managers can most effectively pursue continuous process improvement and positively impact retrograde asset flow times. In Chapter V, we use this analysis to draw conclusions and recommend additional research topics.

V. Conclusions and Recommendations

Overview

In this chapter, we draw conclusions about our research and findings presented in the previous four chapters. Additionally, we provide recommendations for improving performance of the Base Processing Segment of the depot-level reparable pipeline and suggest topics for further research.

The USAF logistics pipeline is an immense system which encompasses all of the activities necessary to sustain a war-fighting capability (3:1). Because of the enormous size of the USAF logistics pipeline, several Air Force studies have been devoted to researching separate portions of the pipeline process. Most of these studies, however, have been of a conceptual nature.

In contrast, our research employs control charting and a simplistic computer simulation in an effort to provide base-level managers with insight into how they can actually accomplish continuous improvement. By combining the active and passive use of control charts, Assignable Causes of variation can be attended to and the quality of the process can be improved.

Conclusions

Data Collection/Use. There is no automated system that collects flow time data for retrograde assets in the Base

Processing Segment of the depot-level reparable pipeline. The SBSS prematurely terminates the base processing days flow time component when a Turn-In (computer transaction) is processed by the base supply activity. As a result, the system does not provide complete asset visibility through the entire Base Processing Segment of the pipeline. This flaw in the flow time computation was remedied by bases participating in the CORONET DEUCE program. For CORONET DEUCE, a manual data collection system was set up to record and monitor retrograde asset flow times associated with F-16 aircraft, avionics parts. In all other cases, however, managers working at the headquarters-level and those assigned to bases not participating in CORONET DEUCE have an inadequate data base for monitoring the entire process.

Statistical Control of the Base Processing Segment. The use of control charts to identify and eliminate Assignable Causes of variation gives managers a powerful tool to bring their processes into statistical control. For example, we constructed and analyzed control charts for five bases participating in CORONET DEUCE II. Four bases (Eielson, Osan, Ramstein, Shaw) were determined to be out of statistical control and in Wheeler's State of Chaos. One base (Moody) was in statistical control but produced some nonconforming product--Wheeler's Threshold State.

Pipeline managers at the study bases did not use control charts to manage their processes. It is highly probable that the Assignable Causes of variation we identified and removed from the Moody AFB data would not normally have been discovered without the aid of control charts. Furthermore, our passive use of control charting at Moody AFB resulted not only in bringing the process into a state of statistical control but also in reducing the mean flow time of retrograde assets through the Base Processing Segment from 33.148 hours to 18.032 hours.

Retrograde Asset Flow Time Reduction. **The use of control charts in the active mode can eliminate Common Causes of variation, which in turn helps reduce average retrograde asset flow time.** The active use of control charts can provide substantial process information to aid pipeline managers in decision making and facilitate continuous process improvement. Only when a process is in control can changes be made to the process which may result in improved performance. Ultimately, retrograde asset flow time reductions become possible because managers can focus on the Common Causes of variation inherent to the system.

The capability of a process depends upon product conformity and the stability of the process over time (29:117). Reductions in retrograde asset flow time hinge on management's understanding of the Base Processing Segment and their ability to keep the process in control. Wheeler states, "...it is only when management supports, in both word and deed, the goal of continual improvement, that it will begin to see increases in both quality and productivity" (29:12). Base-level pipeline managers can display such support, as called for by Wheeler, through the use of active control charting.

By combining modeling and active control charting, managers can gain knowledge of process performance and analyze quality improvement initiatives in a cost efficient manner. For example, the development of a comprehensive simulation model that replicates activities within the depot-level reparable pipeline would make possible the testing and evaluation of proposed process changes prior to implementation. Through modeling and active control charting, pipeline managers may uncover opportunities for process improvement without tampering with the actual system. Then, further testing and evaluation of potential improvements could occur in a limited operational environment for validation. Those pipeline process improvements that actually reduce retrograde asset flow times could then be implemented on a wider scale.

Recommendations

This section contains recommendations for improving the performance of the Base Processing Segment. First, current base-level management information systems require modification to provide the detailed data needed by managers in the pursuit of continual improvement. The manual system being used to collect data for CORONET DEUCE II can serve as a model for measuring Base Processing Segment flow time performance data. Retrograde asset visibility through the base-level pipeline should be the goal of this proposed management information system modification.

Once retrograde asset flow times are made available, the passive use of control charts should be implemented. Assignable Causes of variation can be quickly identified and employees involved with the activity charted can establish ownership of the process. In other words, begin listening to the Voice of the Process. With management involvement and support, process stability is attainable and performance gains become possible. In addition, the continued use of passive control charting will provide base-level managers with a tool to overcome Assignable Causes of variation and to counteract the effects of entropy.

Base-level pipeline managers should focus their process improvement efforts on the Maintenance-To-Supply subsegment. At Moody AFB, retrograde assets accumulated 91 percent of their Base Processing Segment flow time in the Maintenance-To-Supply subsegment. Therefore, relatively small process improvements in this subsegment have the potential to reap large rewards in reducing overall flow time statistics. For example, one non-value added activity that could be eliminated from the Maintenance-To-Supply subsegment is the bench checking of certain retrograde items by maintenance personnel prior to transferring them to supply.

Base-level personnel, such as those working in Base Processing Segment activities, require training in the use of Statistical Process Control tools. The use and understanding of control charts, process flow diagrams, cause-and-effect diagrams, and histograms can play an important role in institutionalizing continual improvement. Because the vast majority of base-level organizations do not have access to a master statistician, the wing quality office should be the focal point for training.

Finally, the Recoverable Consumption Item Requirements System (D041) standard pipeline time value for the base processing days component should be reevaluated. Currently, the D041 uses an average base processing time of 5.2 days. This standard average base processing time is used by headquarters-level managers to determine safety stock levels. Our research at Moody AFB shows that for F-16 avionics parts processed under the two-level maintenance concept, an average processing time of 0.75 days is possible when Assignable Causes of variation are identified and removed using control charts. Based on our analysis, we recommend the D041 standard average base processing days flow time values for these assets be lowered to 1.0 days. Remember, reducing the time that assets reside in the pipeline can lead to reductions in safety stocks and the resulting safety stock reductions can reduce inventory investment.

Suggestions for Future Research

Future research should focus on using Statistical Process Control (SPC) techniques to investigate the five remaining segments of Kettner and Wheatley's Conceptual Model of the Depot-Level Reparable Pipeline (Figure 3). The immense size of their Depot-Level Reparable Pipeline Model necessitates focusing on specific areas rather than the pipeline as a whole.

Furthermore, we recommend a comprehensive study of USAF Logistics Pipeline components from a systems perspective to determine which components of this pipeline would benefit most from the application of SPC techniques. For example, it may be beneficial to track CORONET DEUCE assets through the entire system. A proposed goal would be to identify system constraints and non-value added activities. The use of a detailed simulation model and active control charting can provide valuable information on the system as a whole.

Within the Base Processing Segment, we suggest that a close relationship be established between researchers and base-level managers to facilitate the exchange of information gained through the active and passive use of control charts. Instead of simulating Base Processing Segment flow times, real-time experimentation feedback will provide additional insights into the factors that influence the performance of the base-level pipeline.

Finally, a disconnect exists between the actual base-level processes and the information system that managers rely on to make decisions. Current data collection systems do not provide a complete picture of the Base Processing Segment, nor do they provide the information required to pursue continuous process improvement. A detailed study of base-level management information system requirements may provide valuable recommendations. Providing an automated data base to facilitate control charting and continuous process improvement is imperative.

Summary

The purpose of our in-depth examination of the Base Processing Segment was to identify and provide pipeline managers with the knowledge and tools necessary for reducing process variation that adversely contributes to retrograde asset flow times. Recall from Chapter I, experts estimate that a one-day average reduction in depot-level reparable pipeline flow times will produce inventory cost savings of approximately $50.9 million (23:24). Wheeler provides some insight as to how pipeline process times can be reduced:

> The control chart becomes a powerful tool for continual improvement only as those involved with the process learn how to use the chart to identify and remove Assignable Causes of uncontrolled variation. Every out-of-control point is an opportunity. (29:20)

If pipeline managers want to make significant progress in reducing retrograde asset flow times and eventually reducing the corresponding inventory investments, they must embrace the tools and concepts of Statistical Process Control.

Appendix A - Control Chart Formulas

Control chart centerline and control limits for the subgrouped data were calculated in the following manner:

Given *K* subgroups, where each subgroup consists of *n* observations,

1. Compute the average and range for each of the K subgroups.
2. Compute the Grand Average, $\bar{\bar{X}}$, by averaging each of the K Subgroup Averages.
3. Compute the Average Range, $\bar{R}$, by averaging each of the K Subgroup Ranges.
4. The Central Line For $\bar{X}$-chart is $\bar{\bar{X}}$. The Central Line for R chart is $\bar{R}$.
5. Find the values for A_2, D_3, and D_4, which correspond to the subgroup size *n*.
6. Multiply $\bar{R}$ by $A_2 = A_2\bar{R}$
7. Add the quantity from step 6 to the Grand Average to get the Upper Control Limit for the X Chart: $UCL_x = \bar{\bar{X}} - A_2\bar{R}$
8. Subtract the quantity from step 6 from the Grand Average to get the Lower Control Limit for X chart: $LCL_x = \bar{X} - A_2\bar{R}$
9. Multiply $\bar{R}$ by D_4 to get the Upper Control Limit for the R Chart: $UCL_R = D_4\bar{R}$

10. Multiply $\bar{R}$ by D_3 to get the Lower Control Limit for the R Chart: $LCL_R = D_3\bar{R}$ (29:44).

Statistix 4.0 computer software was used to construct the control charts (28). The formulas used by the Statistix program are the same as shown above. The control limits for the charts are plus or minus three standard deviations. Additionally, zones were established in one standard deviation increments. These zones are not shown on the Statistix printed control charts, but the zones were used in control chart analysis.

Appendix B - Interview Questions

INTERVIEW QUESTIONNAIRE
SQUADRON/FLIGHT/SECTION LEVEL

GENERAL INFORMATION

1. Describe your organizational structure.

    a. What flights/sections are involved in the processing of retrograde reparable assets?
    b. What percentage of their workload does retrograde reparable assets constitute?

2. What goals have been established in your unit regarding the processing of retrograde reparable assets?

    a. Describe how these goals relate to retrograde asset flow?
    b. Describe the measures your unit uses to determine your success in meeting these goals?

PHYSICAL INFORMATION

1. Describe the physical layout of your squadron.

2. Who transports retrograde reparable assets to and from your repair cycle support section?

    a. Are trips regularly scheduled? If so, how often?
    b. Which section moves retrograde assets to base transportation?

3. Describe any impediment your current layout may have on productivity?

SYSTEM INFORMATION

1. Describe the flow of retrograde reparable assets at Moody AFB?

   a. When do assets enter your unit?
   b. What actions do you take to move/process these assets?
   c. What actions do you take to correct discrepancies?

2. Who are your internal and external customers?

   a. Describe your relationship with your internal customers?
   b. Describe your relationship with your external customers?

3. When do you consider a retrograde reparable asset at Moody AFB outside of your area of responsibility?

PERFORMANCE INFORMATION

1. What data are collected to monitor the performance of your section regarding reparable asset processing?

   a. What are your data sources?
   b. What form is the data collected (time,units,averages)?
   c. How often is the data collected?
   d. How is the data analyzed?
   e. How is the analysis presented?

2. Describe how managers use the data in decisions related to retrograde asset flow?

   a. What standard are you measured against?
   b. Comment to the appropriateness of this standard?

3. Provide an example of how retrograde asset flow data effected a change in your procedures?

4. What data is reported to HQ ACC concerning reparable asset flow?

5. Other than standard base supply data reports, what unique management tools have you devised to improve

reparable asset processing?

INTERVIEWEE INFORMATION

Date: __________
Location: ______________________

Flight/Section Name: ____________________
Telephone: _____________

Name and Duty Title of Interviewee
____
____

Comments:

Appendix C - CORONET DEUCE II Stock Numbers

Following are the stock numbers of the CORONET DEUCE reparable assets used in our study. The flow times of these stock numbers through the Base Processing Segment was the characteristic control charted.

National Stock Number:

1260-01-193-8861
1260-01-251-1150
1270-01-233-0011
1270-01-238-3362
1270-01-256-6538
1270-01-309-3077
1270-01-330-8895
1270-01-746-8162
1270-99-746-8162
1290-01-322-3711
5865-01-053-5396
5865-01-080-5675
5865-01-154-9125
5865-01-324-9103
5895-01-112-6380
5895-01-154-9125
5895-01-212-2950
5895-01-242-2033
5985-01-212-2950
5895-01-310-2157
5998-01-189-6233
5999-01-080-3978
5999-01-189-6233
6605-01-256-2380
6610-01-089-1018
6610-01-308-1859
6615-01-042-7834
6615-01-149-6398
6615-01-316-7226
6615-01-351-7337
6615-01-361-9746

Appendix D - GPSS/H Simulation Model

```
        SIMULATE
*
*       Storage Declaration Segment
*
        STORAGF     S(MAINT),5/S(SUP),10/S(TRANS),10
*
*       Define Ampervariables
*
        REAL        &EXP,&MIN(6),&MODE(6),&MAX(6),&SEGSUM
        LET         &EXP=13.5
        LET         &MIN(1)=3.48
        LET         &MODE(1)=10
        LET         &MAX(1)=25.00
        LET         &MIN(2)=.02
        LET         &MODE(2)=.05
        LET         &MAX(2)=.17
        LET         &MIN(3)=.02
        LET         &MODE(3)=1.25
        LET         &MAX(3)=3.67
        LET         &MIN(4)=.08
        LET         &MODE(4)=.2
        LET         &MAX(4)=.54
        LET         &MIN(5)=.08
        LET         &MODE(5)=2.50
        LET         &MAX(5)=15.32
        LET         &MIN(6)=3.48
        LET         &MODE(6)=36.00
        LET         &MAX(6)=337.04
*
*       Define Output File
*
 OUT    FILEDEF     'B:EXP23.DAT'
*
*
*       GPSS/H Block Section
*
        GENERATE    RVEXPO(1,&EXP),,,,,4PL  Parts arrive
exponentially with a mean of 16.55 hours
        ASSIGN      TIMEIN,AC1,PL  Entry time is recorded in
xact attribute
*
*       Maintenance-to-Supply Subsegment
*
        QUEUE       MTSQ              Begin collecting waiting
time stats
        TRANSFER    .96,BAD,GOOD      Transfer 99% of parts to
normal processing
```

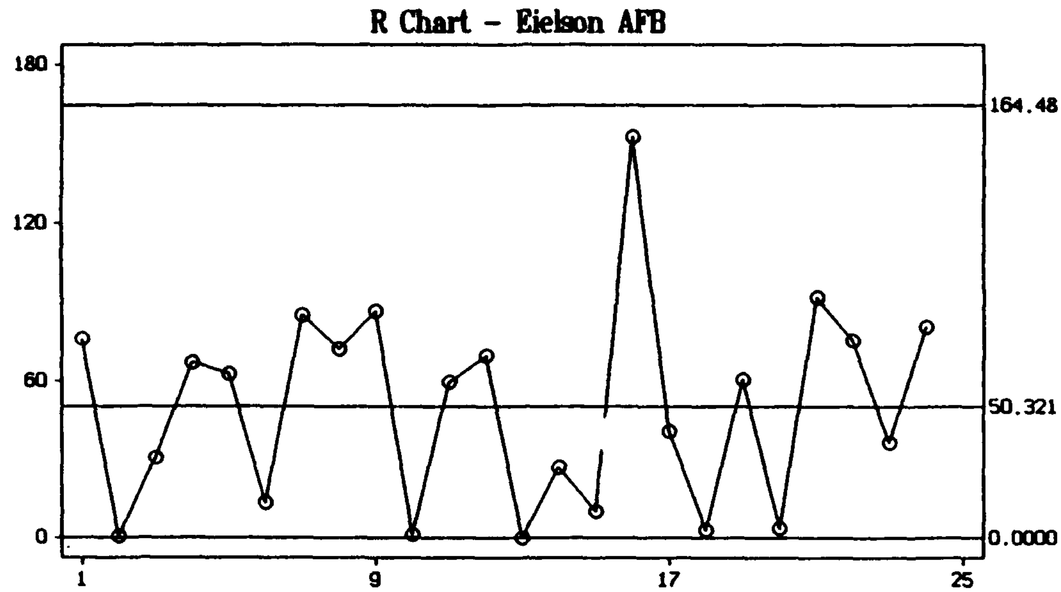
```
*
GOOD    ENTER       MAINT               Part captures one of five
workers
        ADVANCE     RVTRI(2,&MIN(1),&MODE(1),&MAX(1))  Parts
progress through the M-T-S subsegment
        LEAVE       MAINT               Worker released
        ASSIGN      MTSTIME,(AC1-PL(TIMEIN)),PL  Identify
attribute for M-T-S time and record solution
        DEPART      MTSQ                Stop collecting waiting
time stats
        TRANSFER    ,NEXT
*
BAD     ENTER       MAINT                Uncommon part captures one
of five workers
        ADVANCE     RVTRI(6,&MIN(6),&MODE(6),&MAX(6)) Uncommon
parts progress through the S-P subsegment
        LEAVE       MAINT                Part frees position on
processing line
        ASSIGN      MTSTIME,(AC1-PL(MTSTIME)-PL(TIMEIN)),PL
Identify attribute for S-P time and record solution
        DEPART      MTSQ                Stop collecting waiting
time stats

*
*       Supply Processing Subsegment
*
NEXT    QUEUE       SUPQ                Begin collecting waiting
time stats
        TRANSFER    .96,UNCMMN,COMMON  Transfer 99% of parts
to common supply processing
*
COMMON ENTER        SUP                 Part captures position on
processing line
        ADVANCE     RVTRI(3,&MIN(2),&MODE(2),&MAX(2))  Parts
progress through the S-P subsegment
        LEAVE       SUP                 Part frees position on
processing line
        ASSIGN      SPTIME,(AC1-PL(MTSTIME)-PL(TIMEIN)),PL
Identify attribute for S-P time and record solution
        DEPART      SUPQ                Stop collecting waiting
time stats
        TRANSFER    ,TRUCK
*
UNCMMN ENTER        SUP                 Uncommon parts capture
position on processing line
        ADVANCE     RVTRI(4,&MIN(3),&MODE(3),&MAX(3)) Uncommon
parts progress through the S-P subsegment
        LEAVE       SUP                 Part frees position on
processing line
        ASSIGN      SPTIME,(AC1-PL(MTSTIME)-PL(TIMEIN)),PL
Identify attribute for S-P time and record solution
        DEPART      SUPQ                Stop collecting waiting
time stats
```

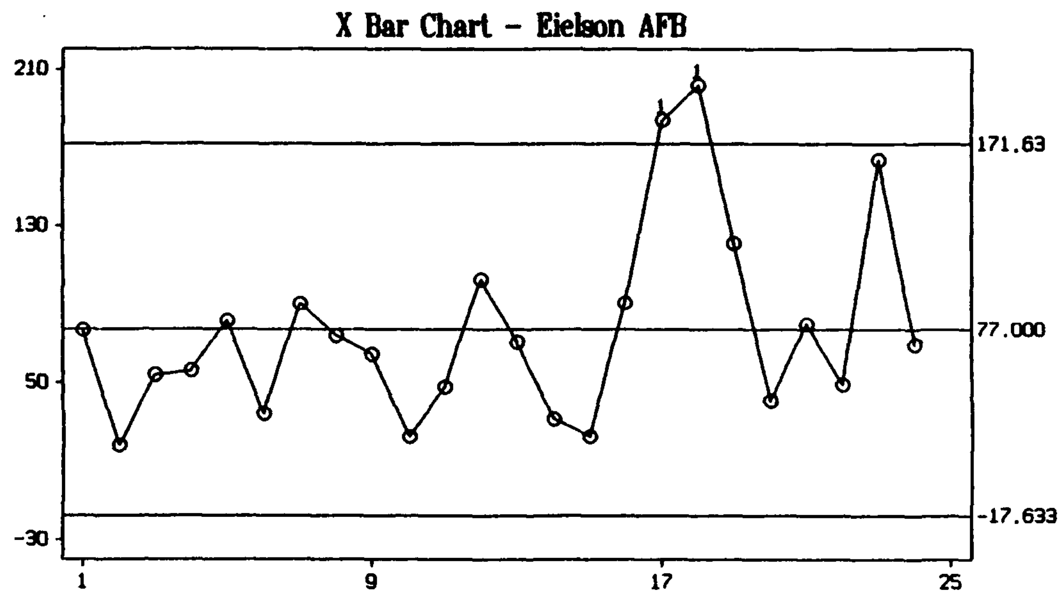
```
*
*      Supply-to-Transportation Subsegment
*
TRUCK  QUEUE      TRANSQ          Collect waiting time stats
       TRANSFER   .96,EXCPTN,STNDRD  Transfer 99% of parts
to standard S-T processing
*
STNDRD ENTER      TRANS           Part capture position in
subsegment
       ADVANCE    RVTRI(5,&MIN(4),&MODE(4),&MAX(4))  Parts
progress through the S-T-T subsegment
       LEAVE      TRANS           Part frees position in
subsegment
       ASSIGN
STTTIME,(AC1-PL(SPTIME)-PL(MTSTIME)-PL(TIMEIN)),PL  Identify
attribute for S-T-T time and record solution
       DEPART     TRANSQ          Stop collecting waiting
time stats
       TRANSFER   ,END
*
EXCPTN ENTER      TRANS           Exception part capture
position in subsegment
       ADVANCE    RVTRI(6,&MIN(5),&MODE(5),&MAX(5))  Parts
progress through the S-T-T subsegment
       LEAVE      TRANS           Part frees position in
subsegment
       ASSIGN
STTTIME,(AC1-PL(SPTIME)-PL(MTSTIME)-PL(TIMEIN)),PL  Identify
attribute for S-T-T time and record solution
       DEPART     TRANSQ          Stop collecting waiting
time stats
*
*      End of Base Processing Segment
*
END    BLET       &SEGSUM=PL(MTSTIME)+PL(SPTIME)+PL(STTTIME)
       BPUTPIC
FILE=OUT,LINES=1,(PL(MTSTIME),PL(SPTIME),PL(STTTIME),&SEGSUM
)
   **.***     **.***     **.***     **.***
       TERMINATE  1          Reparable parts leave the Base
Processing Segment of the DLRP
*
*         GPSS/H Control Statements
*
       START      125
       END
```

Appendix E - Base Processing Segment Control Charts

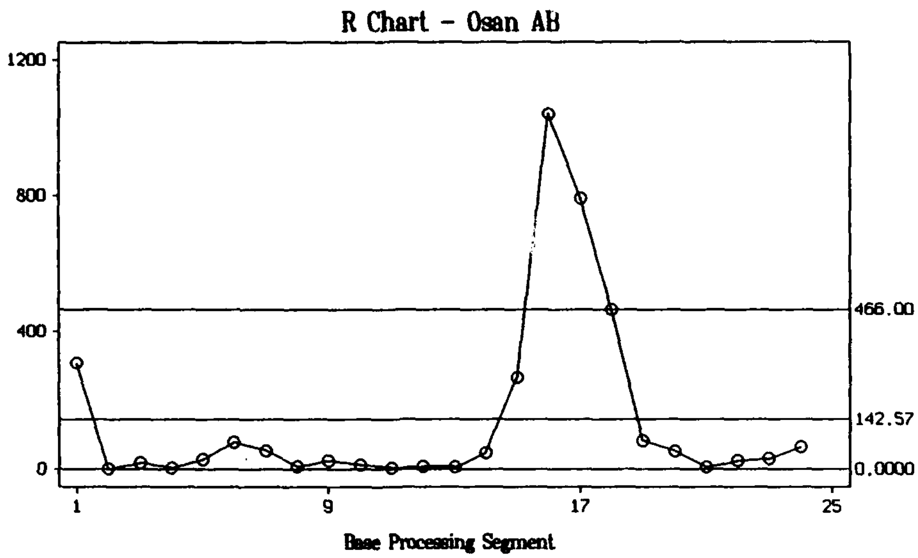
This Appendix contains the control charts from the Base Processing Segment analysis. The charts are arranged by Base.



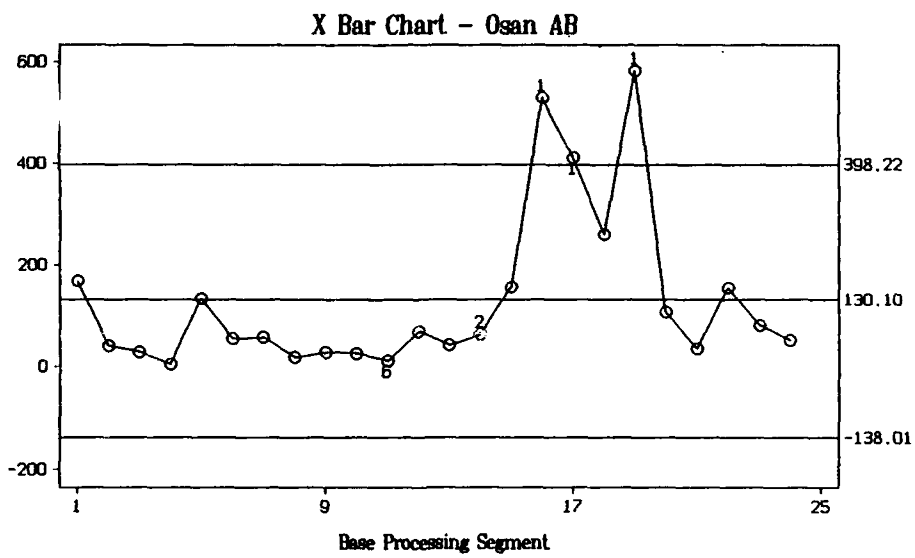
Base Processing Segment
sigma 44.611



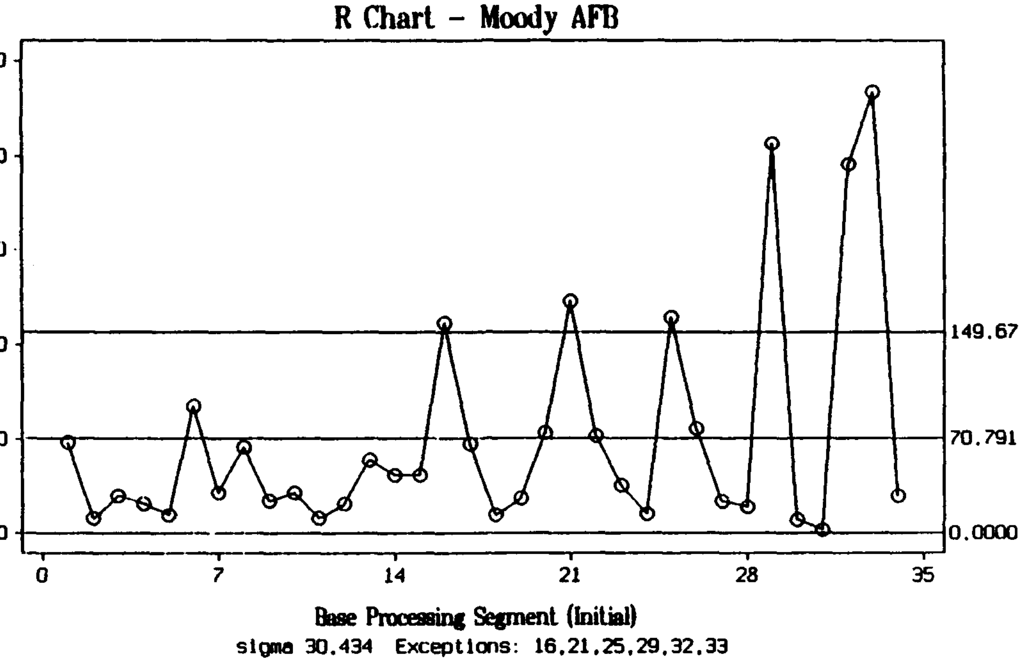
Base Processing Segment
sigma 44.611 E(R bar) 50.321 Exceptions: 17,18



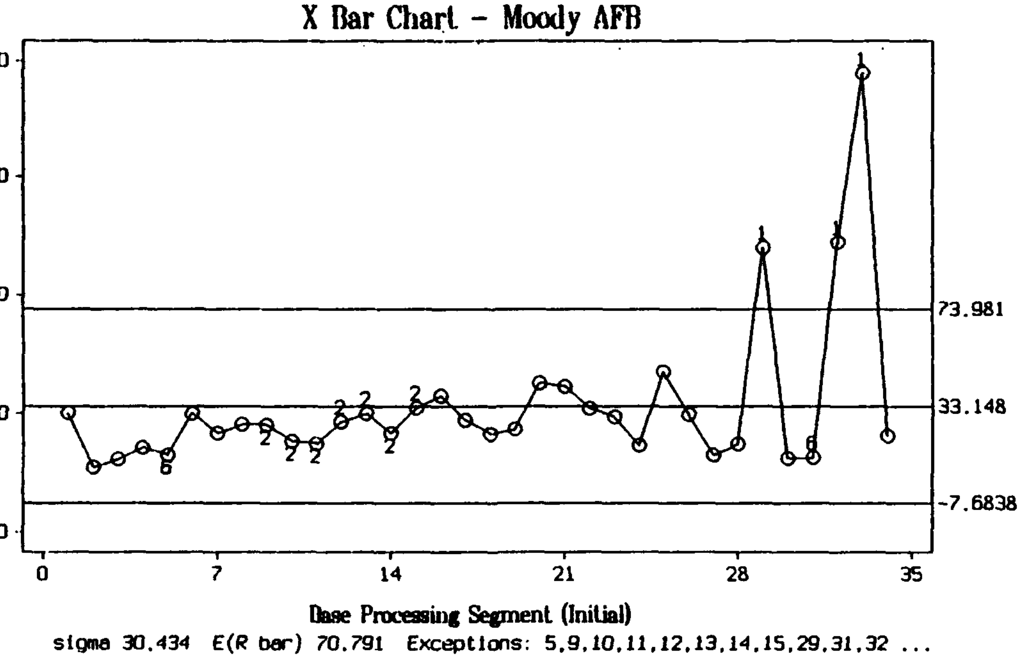
sigma 126.39 Exceptions: 16,17



sigma 126.39 E(R bar) 142.57 Exceptions: 11,14,16,17,19

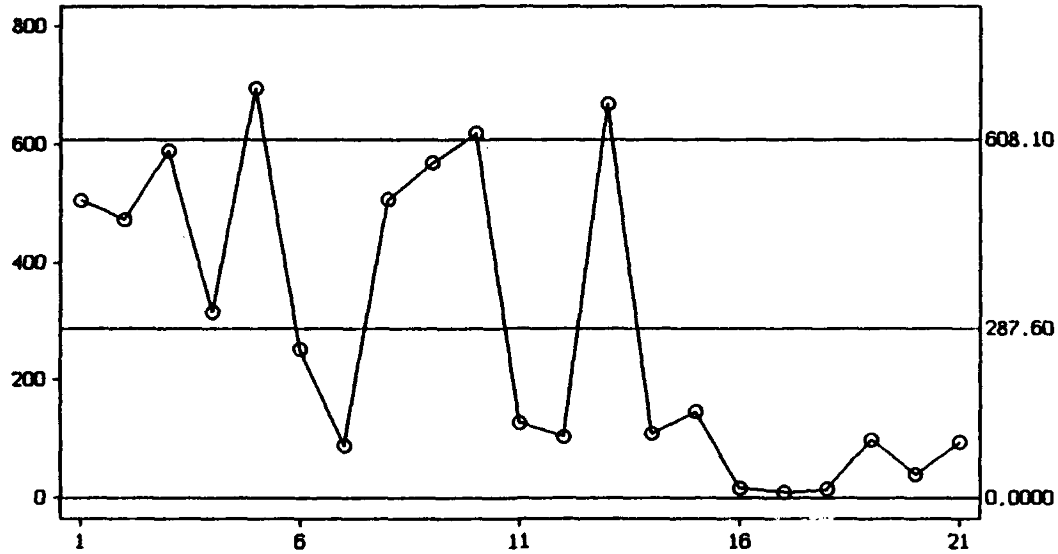


R Chart - Moody AFB
350
280
210
140
70
0
149.67
70.791
0.0000
0
7
14
21
28
35
Base Processing Segment (Initial)
sigma 30.434 Exceptions: 16,21,25,29,32,33



X Bar Chart - Moody AFB
180
130
80
30
-20
73.981
33.148
-7.6838
0
7
14
21
28
35
Base Processing Segment (Initial)
sigma 30.434 E(R bar) 70.791 Exceptions: 5,9,10,11,12,13,14,15,29,31,32 ...

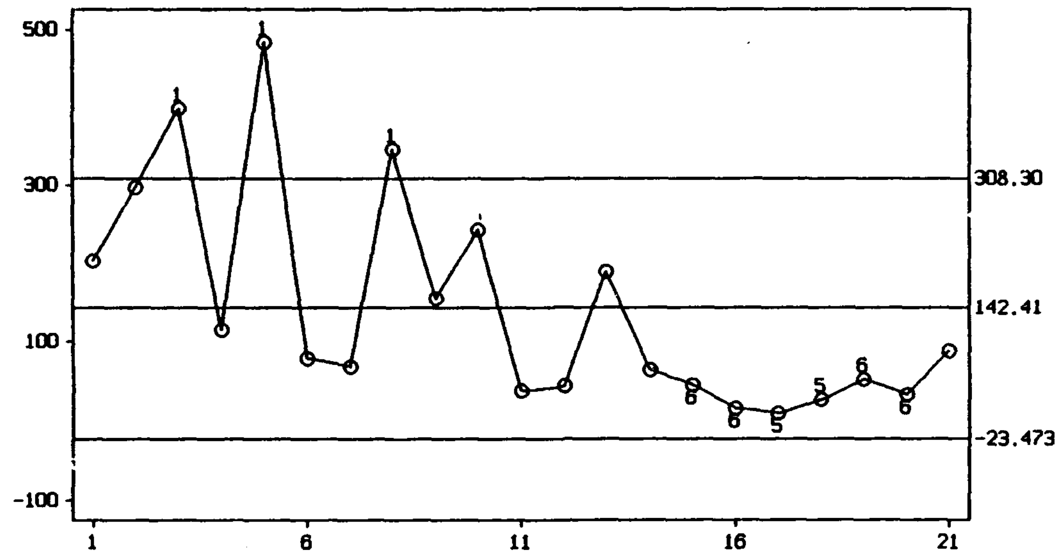
R Chart - Ramstein AB



Base Processing Segment

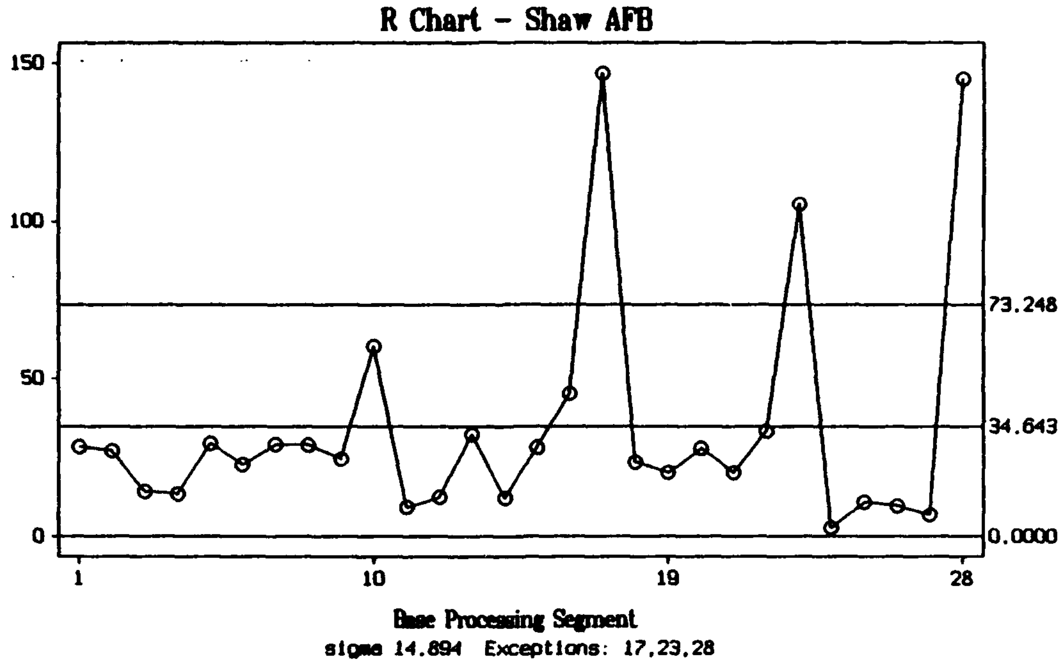
sigma 123.64 Exceptions: 5,10,13

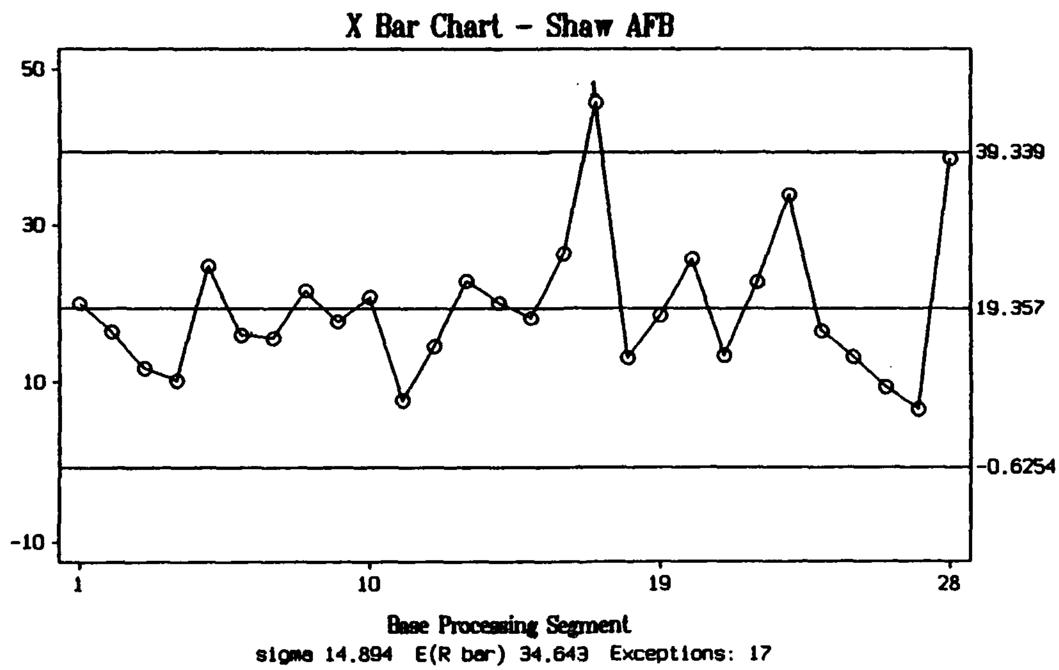
X Bar Chart - Ramstein AB



Base Processing Segment

sigma 123.64 E(R bar) 287.60 Exceptions: 3,5,8,15,16,17,18,19,20

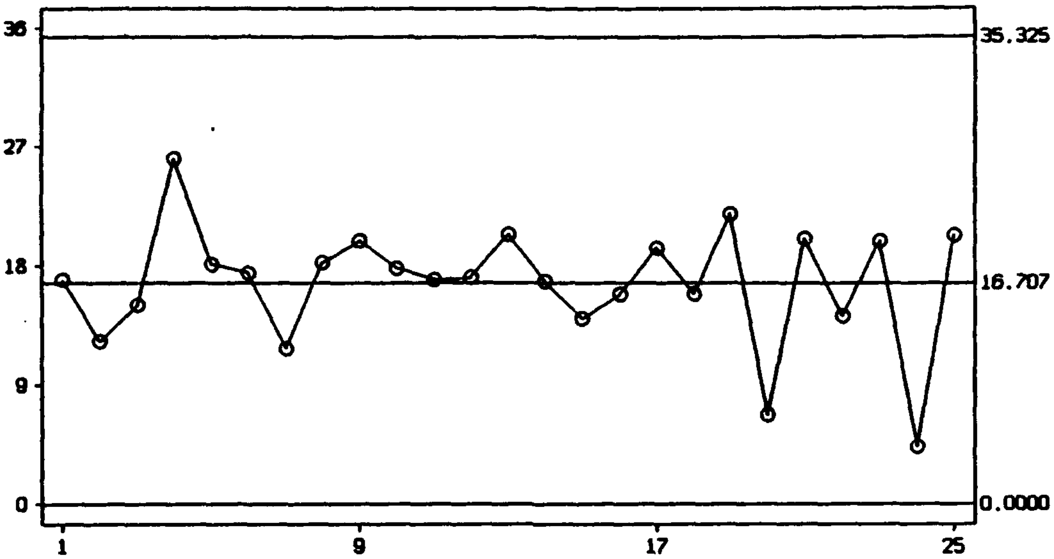

R Chart - Shaw AFB
150
100
50
0
73.248
34.643
0.0000
1
10
19
28
Base Processing Segment
sigma 14.894 Exceptions: 17,23,28


X Bar Chart - Shaw AFB
50
30
10
-10
39.339
19.357
-0.6254
1
10
19
28
Base Processing Segment
sigma 14.894 E(R bar) 34.643 Exceptions: 17

Appendix F - Experiment Control Charts

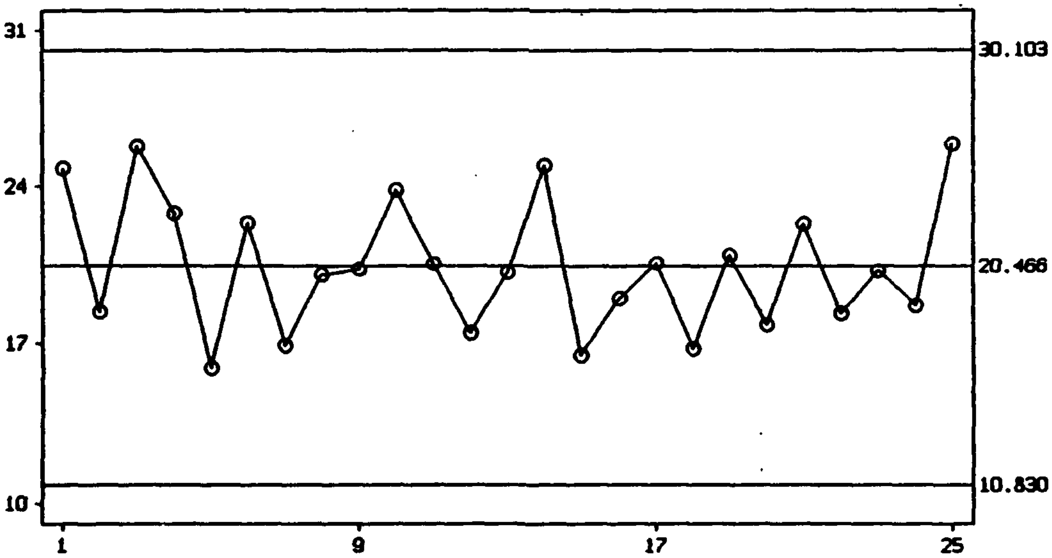
This Appendix contains the control charts from the one-factor experiment. The charts arranged by Test number.

R Chart - EXPERIMENT

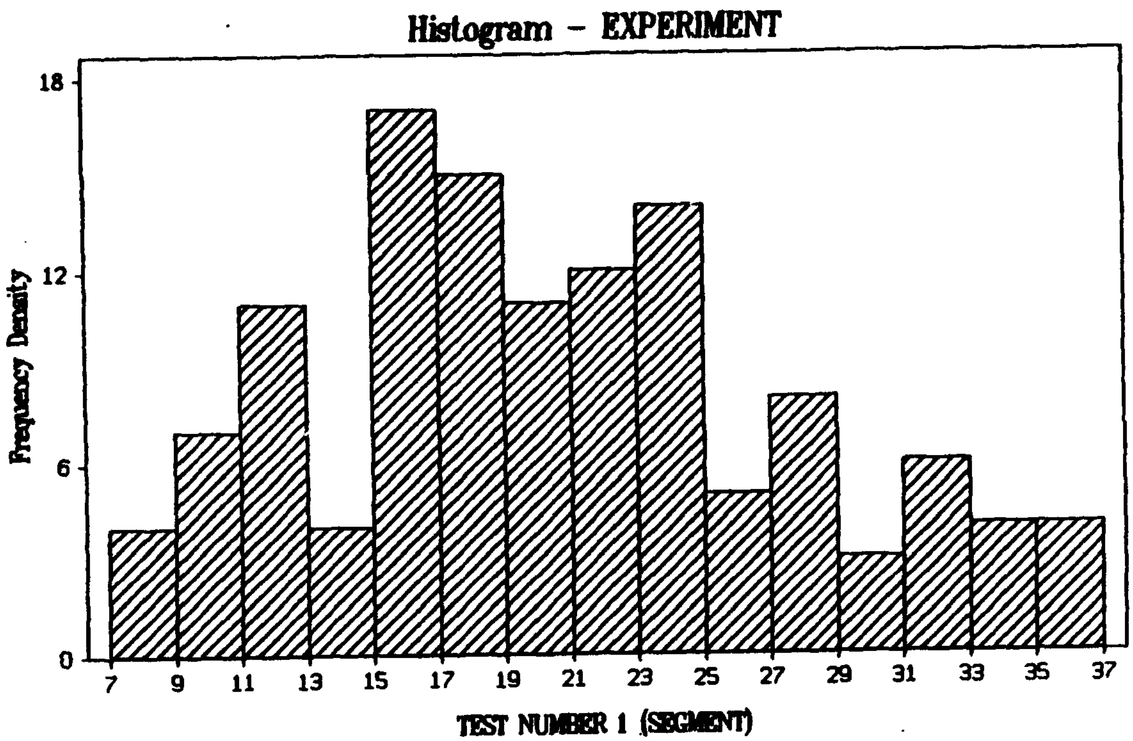


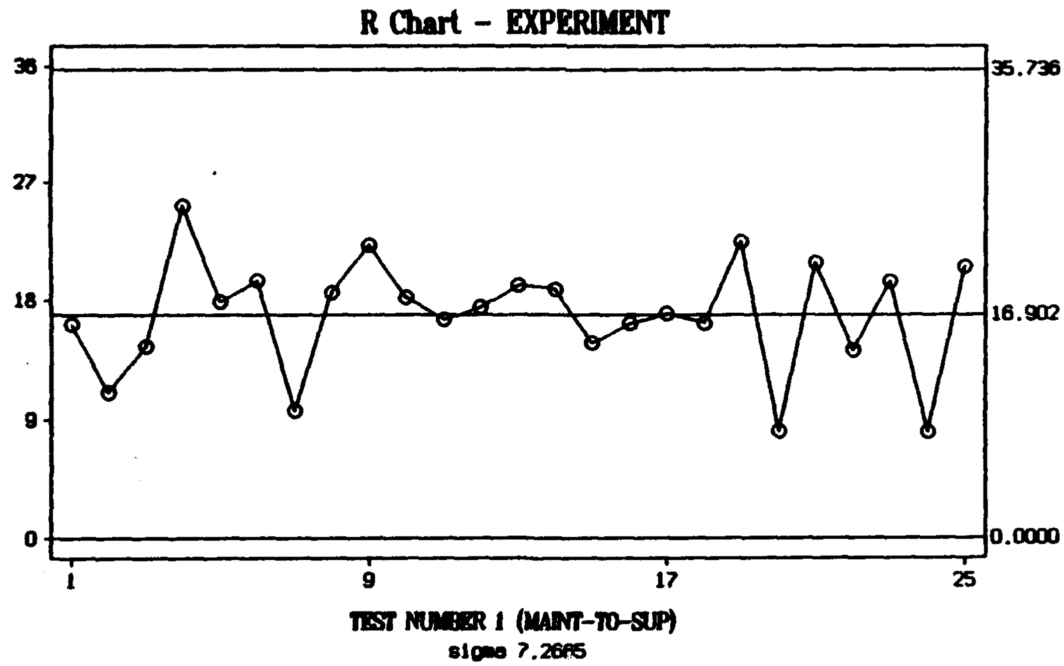
TEST NUMBER 1 (SEGMENT)
sigma 7.1828

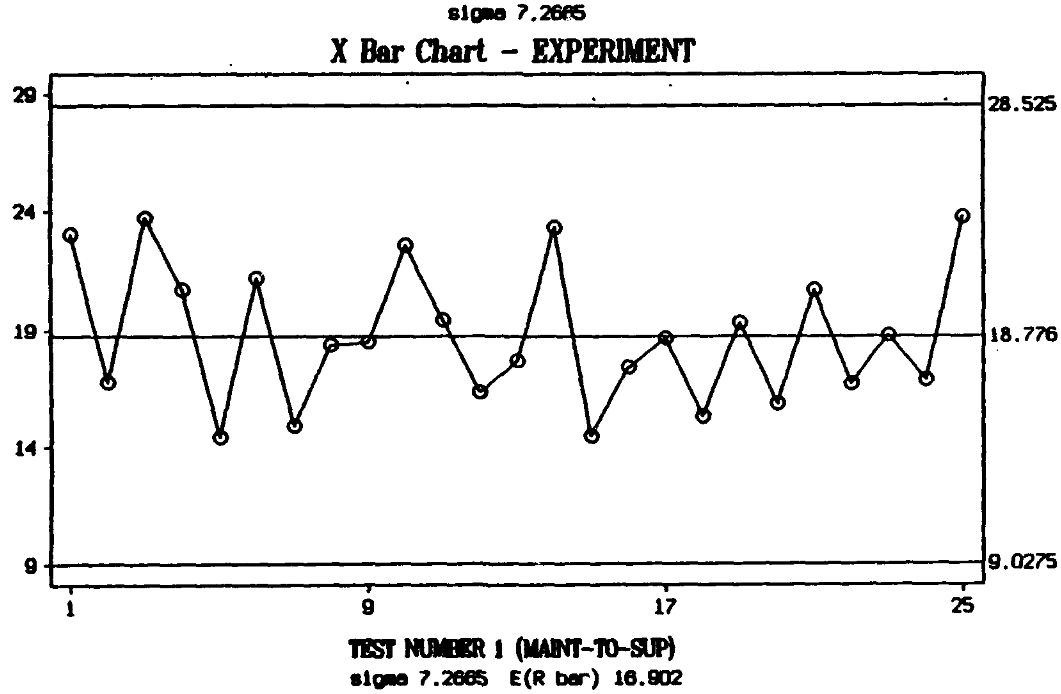
X Bar Chart - EXPERIMENT

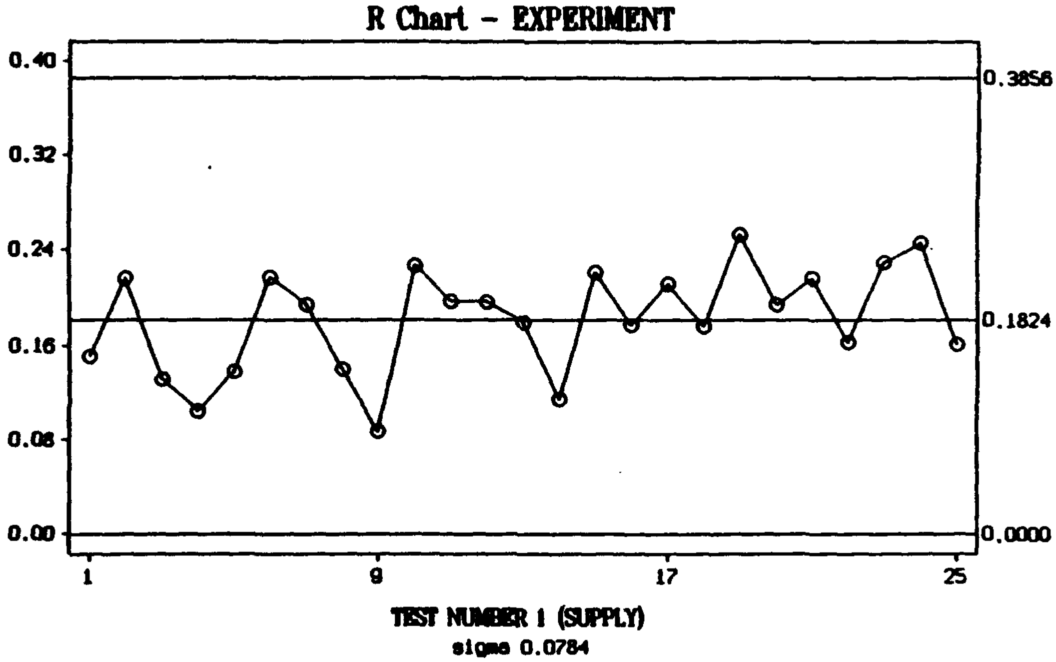


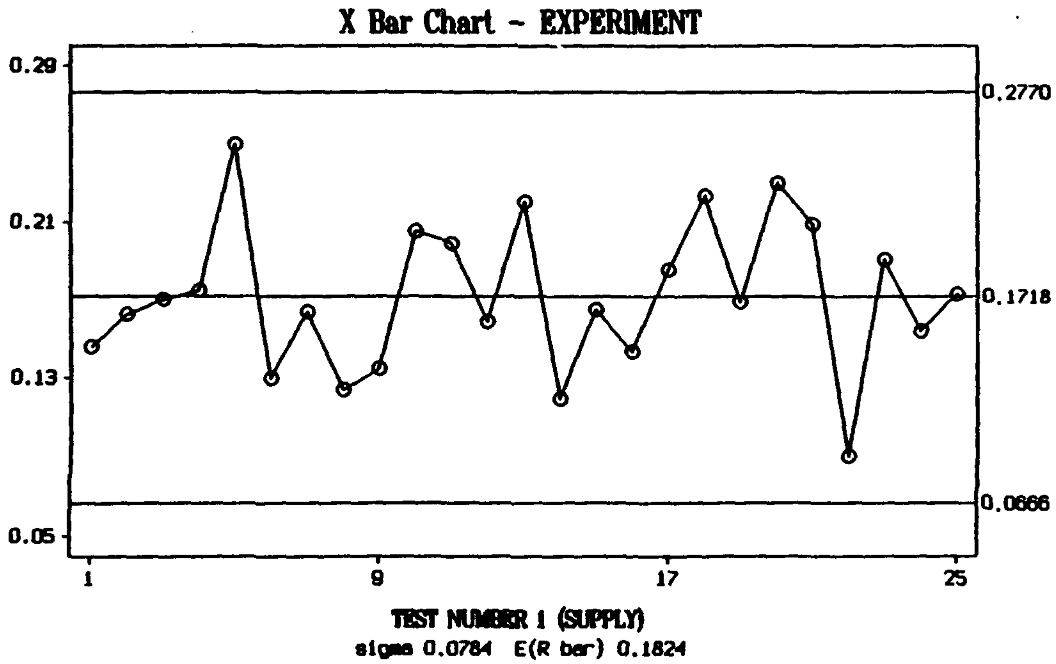
TEST NUMBER 1 (SEGMENT)
sigma 7.1828 E(R bar) 16.707


Histogram - EXPERIMENT
Frequency Density
18
12
6
0
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
TEST NUMBER 1 (SEGMENT)

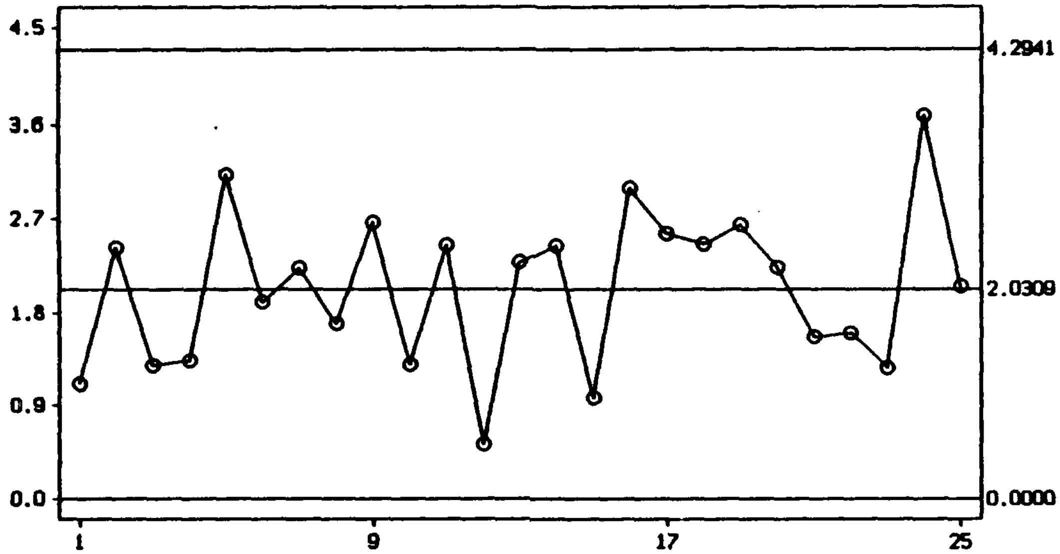

R Chart - EXPERIMENT
36
27
18
9
0
35.736
16.902
0.0000
1
9
17
25
TEST NUMBER 1 (MAINT-TO-SUP)
sigma 7.2685


X Bar Chart - EXPERIMENT
29
24
19
14
9
28.525
18.776
9.0275
1
9
17
25
TEST NUMBER 1 (MAINT-TO-SUP)
sigma 7.2665 E(R bar) 16.902


R Chart - EXPERIMENT
0.40
0.32
0.24
0.16
0.08
0.00
0.3856
0.1824
0.0000
1
9
17
25
TEST NUMBER 1 (SUPPLY)
sigma 0.0784

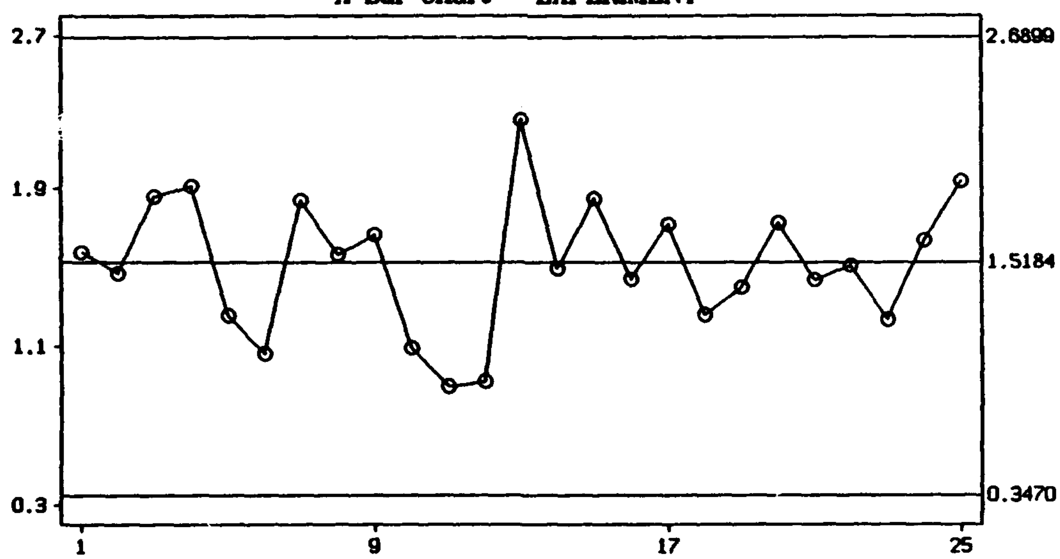

X Bar Chart - EXPERIMENT
0.29
0.21
0.13
0.05
0.2770
0.1718
0.0666
1
9
17
25
TEST NUMBER 1 (SUPPLY)
sigma 0.0784 E(R bar) 0.1824

R Chart - EXPERIMENT

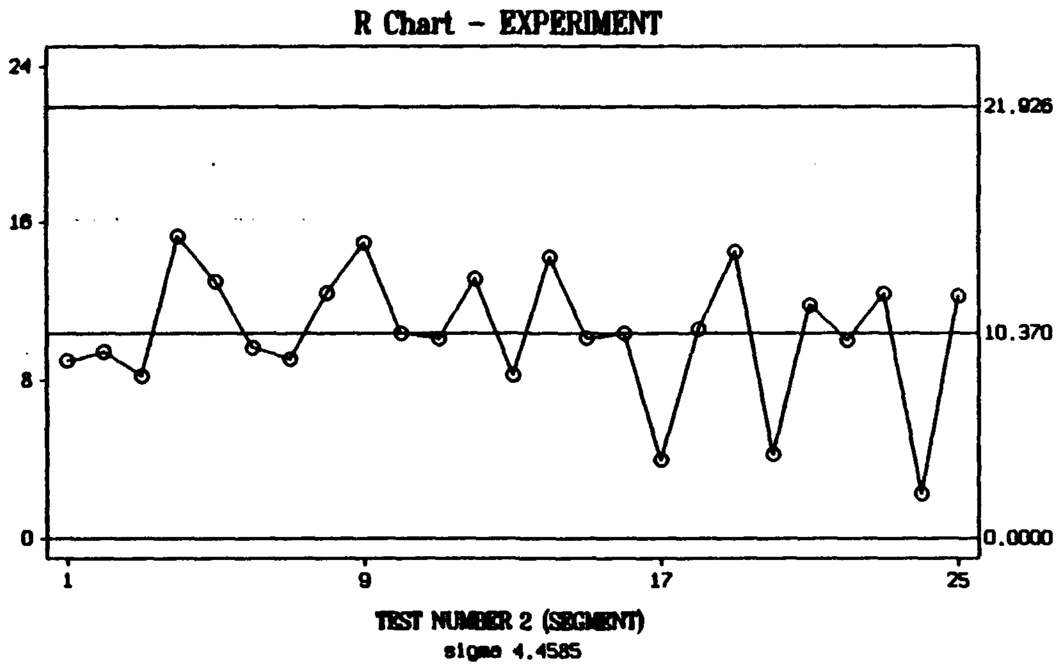


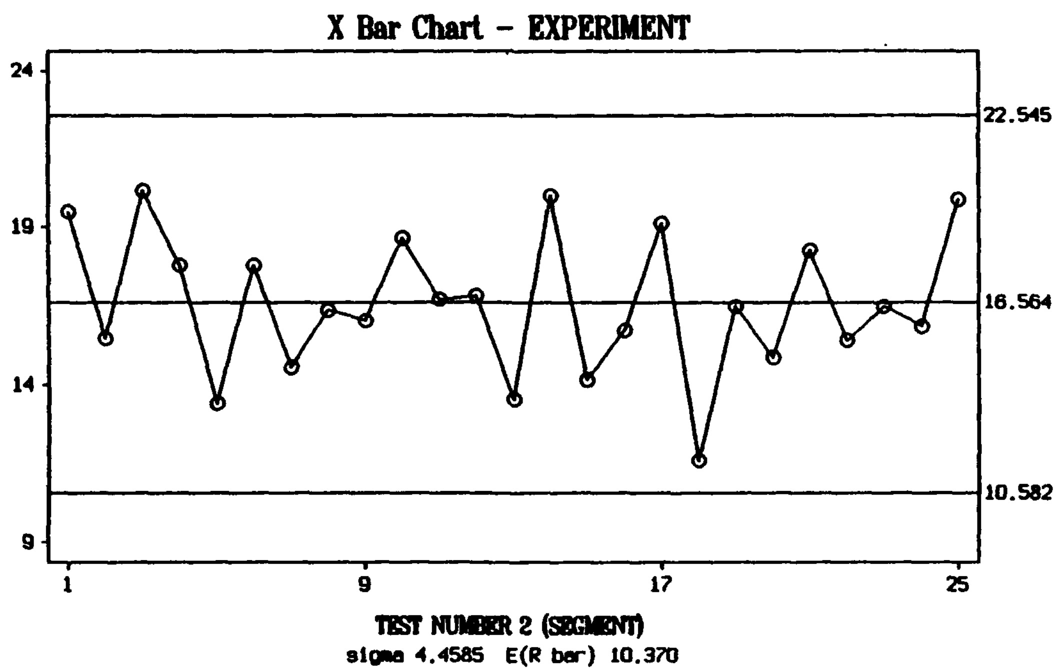
TEST NUMBER 1 (SUP-TO-TRANS)
sigma 0.8731

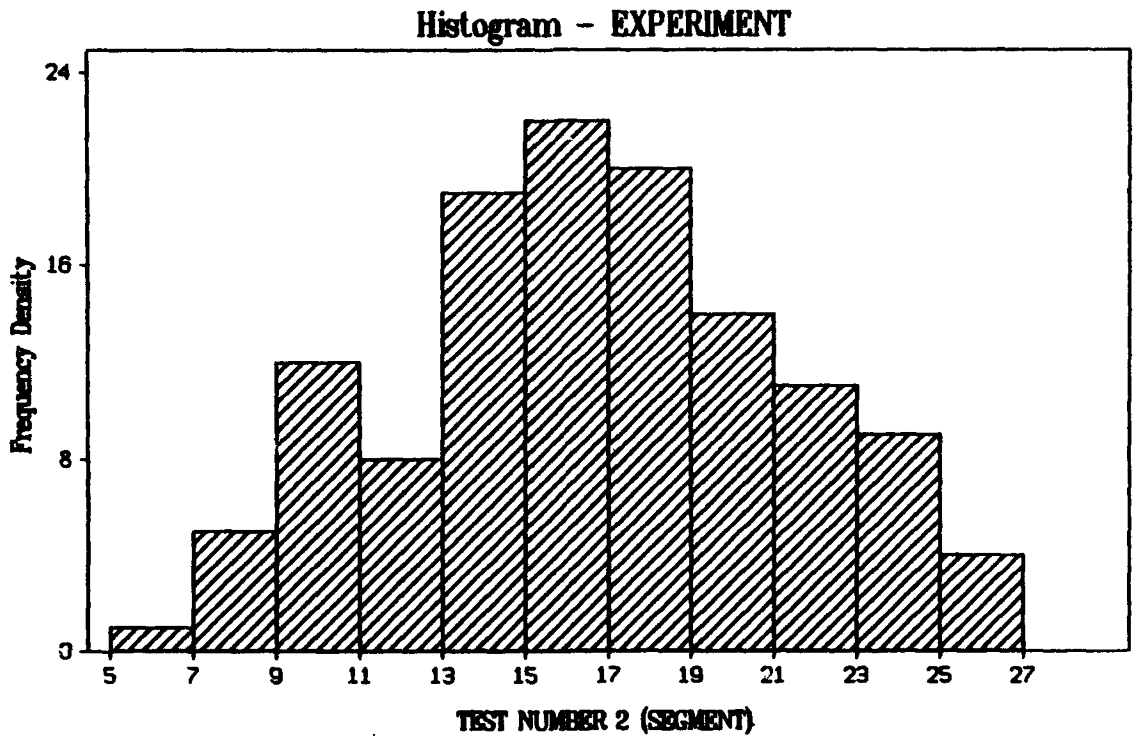
X Bar Chart - EXPERIMENT



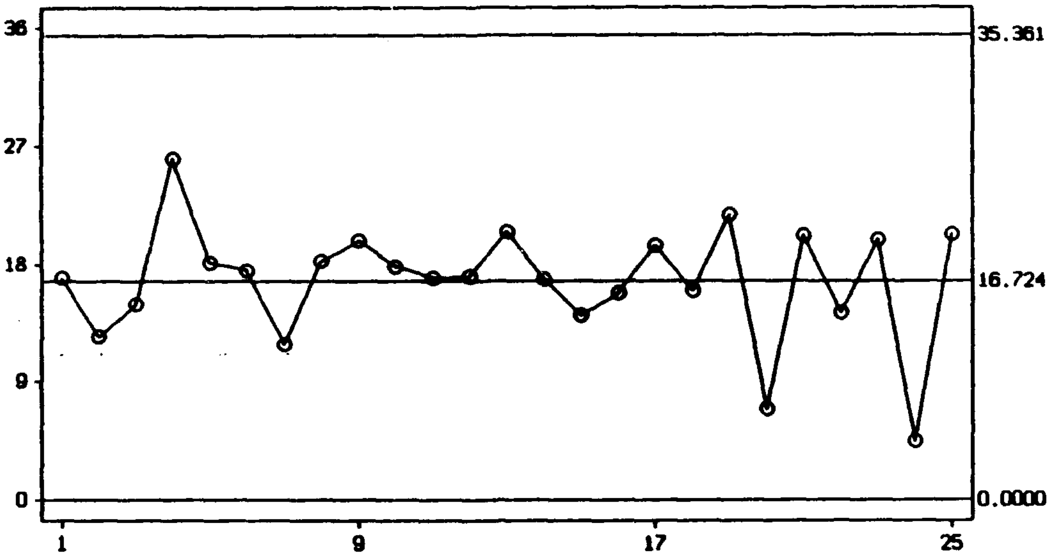
TEST NUMBER 1 (SUP-TO-TRANS)
sigma 0.8731 E(R bar) 2.0309


R Chart - EXPERIMENT
24
16
8
0
21.926
10.370
0.0000
1
9
17
25
TEST NUMBER 2 (SEGMENT)
sigma 4.4585


X Bar Chart - EXPERIMENT
24
19
14
9
22.545
16.564
10.582
1
9
17
25
TEST NUMBER 2 (SEGMENT)
sigma 4.4585 E(R bar) 10.370

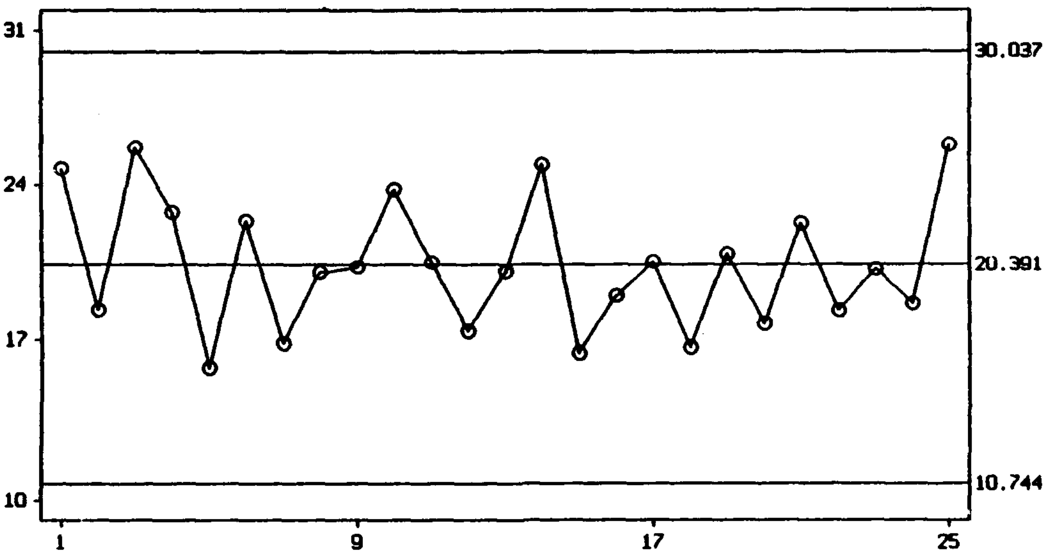

Histogram - EXPERIMENT
24
16
8
0
Frequency Density
5
7
9
11
13
15
17
19
21
23
25
27
TEST NUMBER 2 (SEGMENT)

R Chart - EXPERIMENT

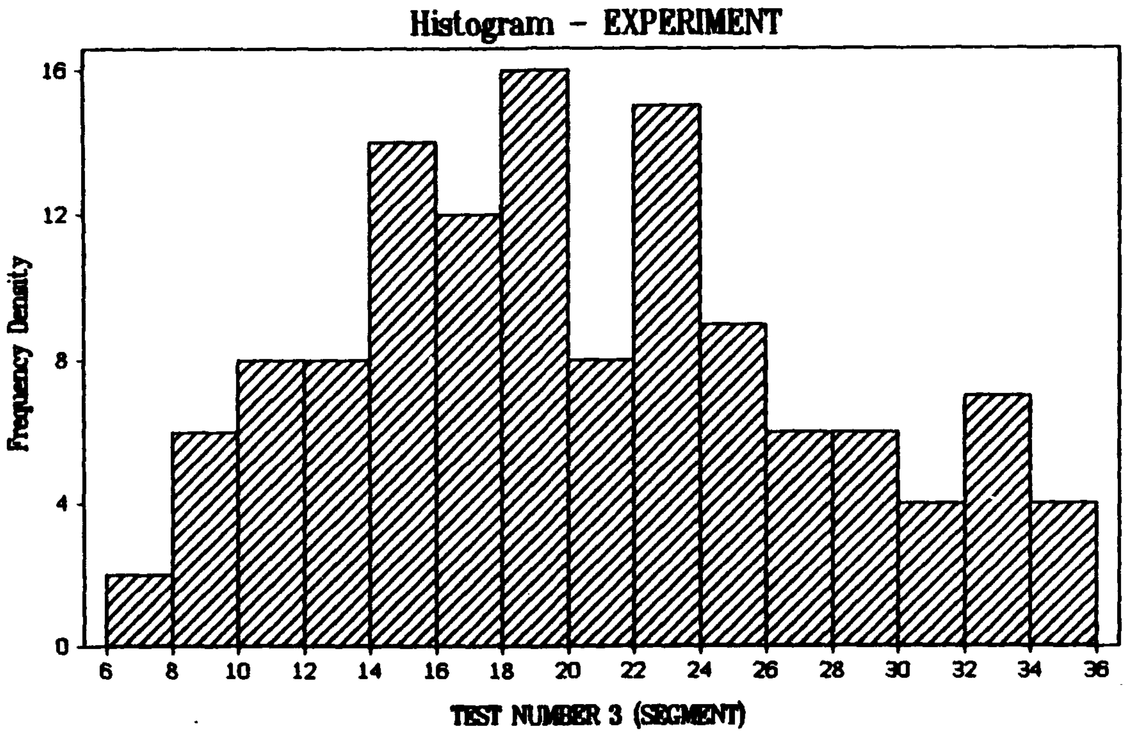


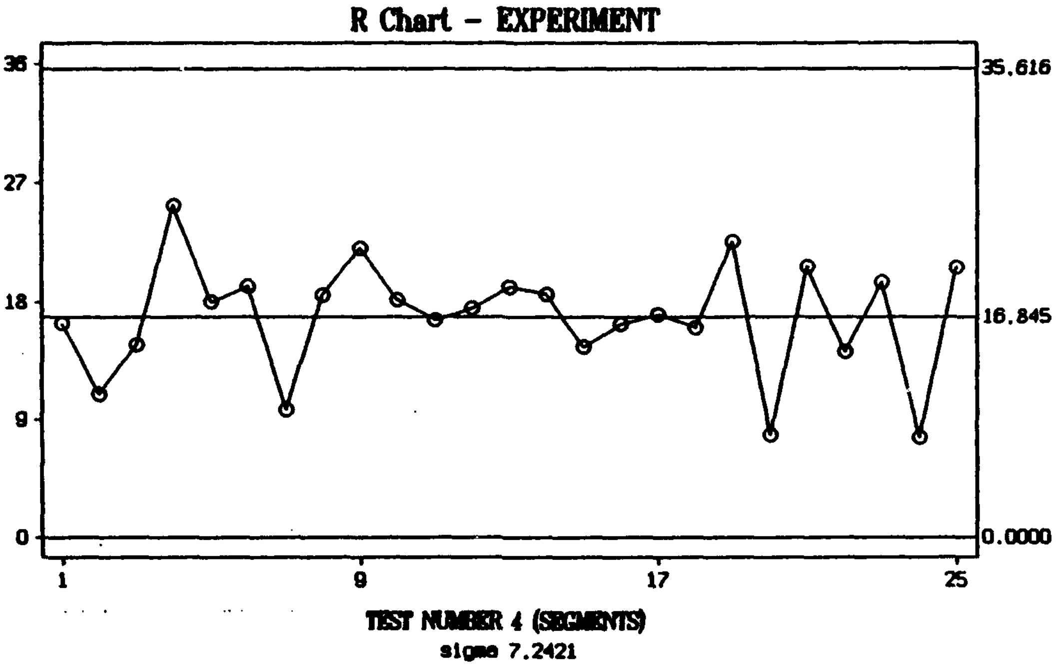
TEST NUMBER 3 (SEGMENT)
sigma 7.1901

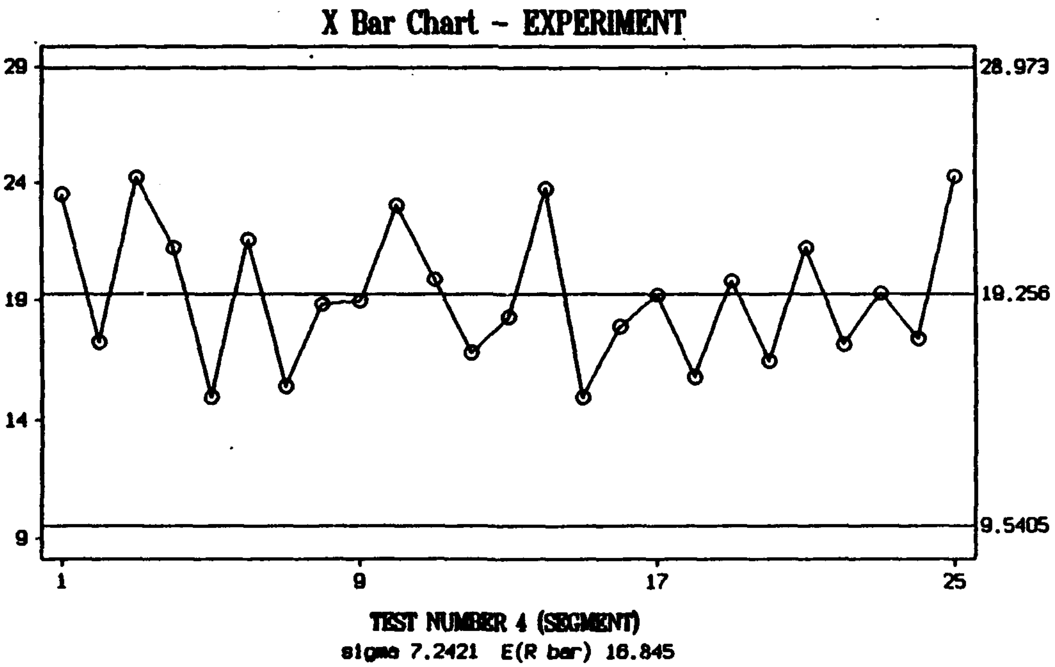
X Bar Chart - EXPERIMENT

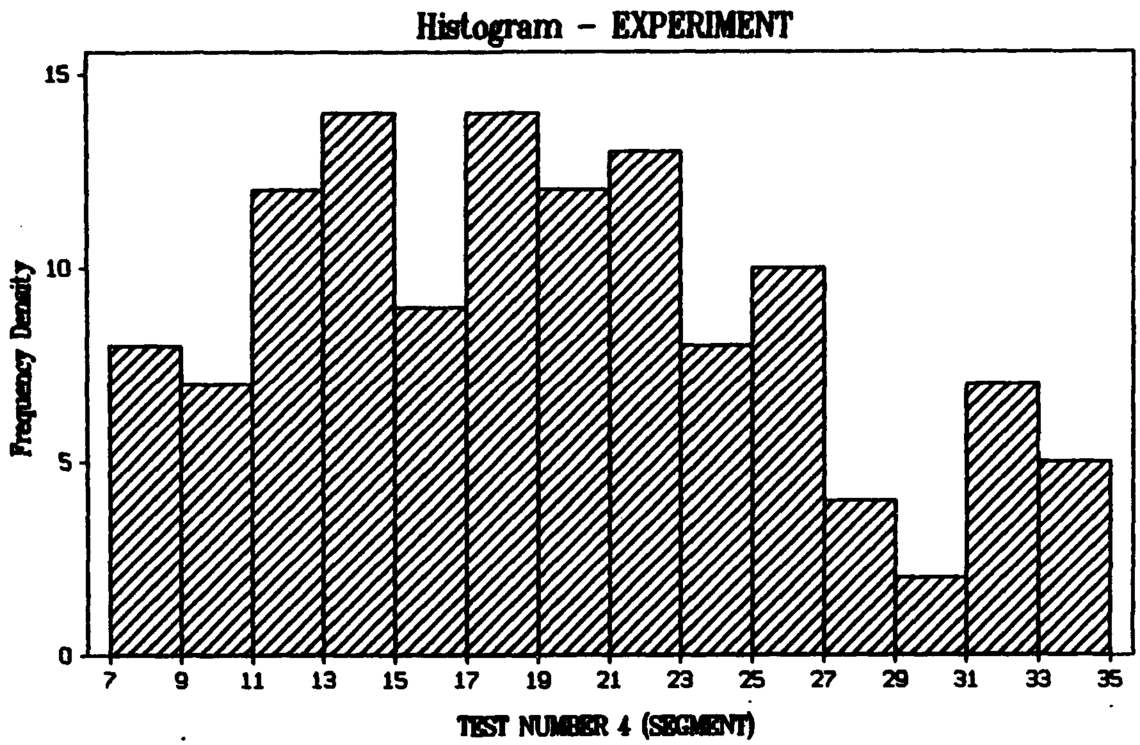


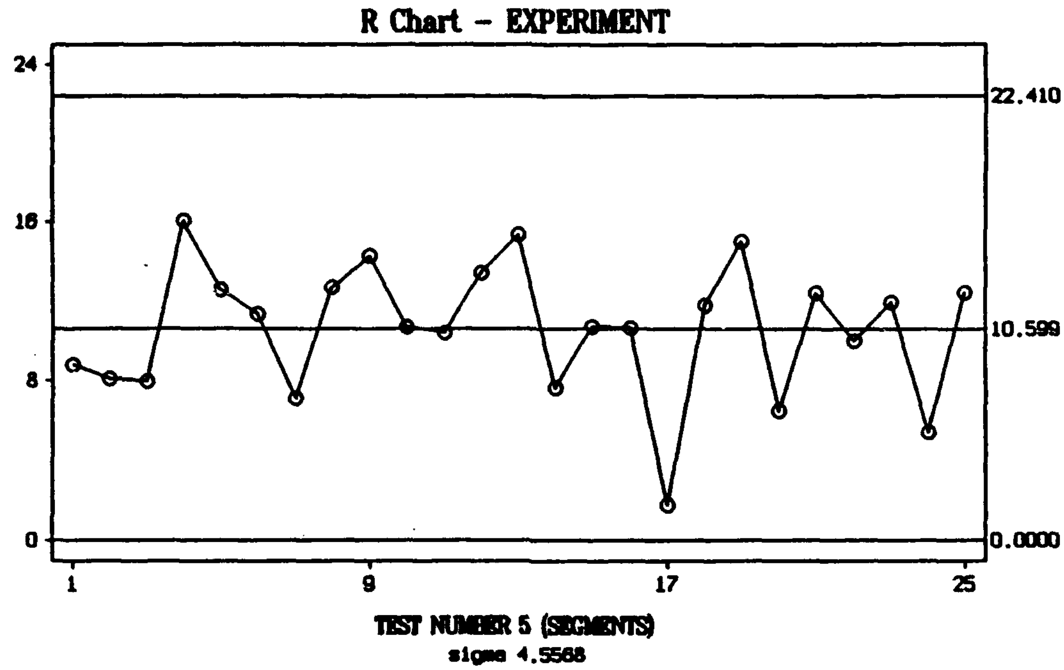
TEST NUMBER 3 (SEGMENT)
sigma 7.1901 E(R bar) 16.724

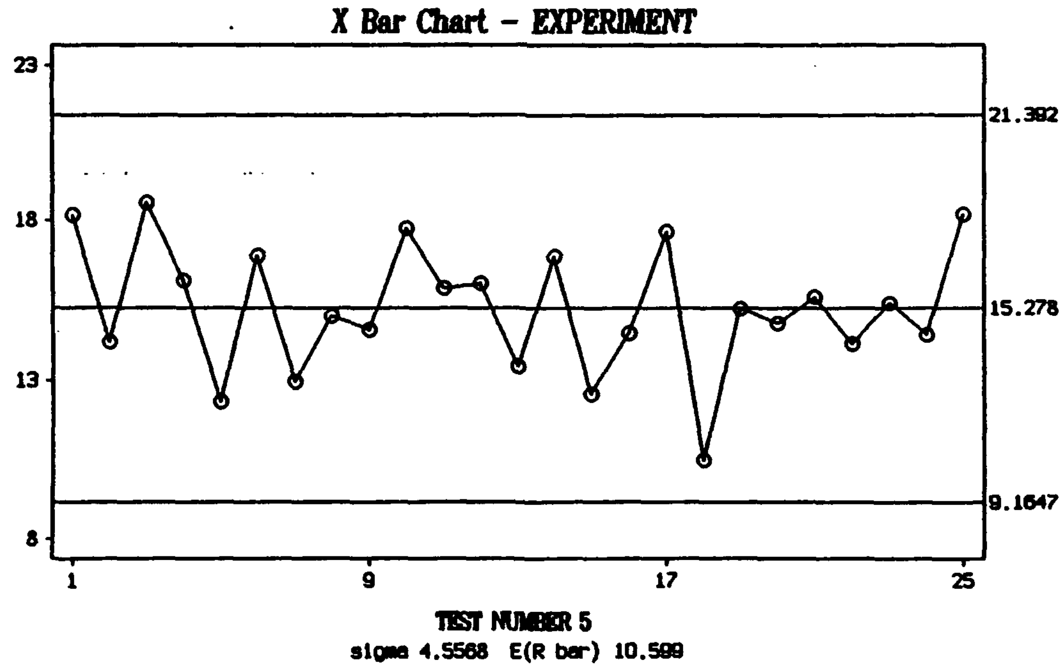

Histogram - EXPERIMENT
16
12
8
4
0
Frequency Density
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
TEST NUMBER 3 (SEGMENT)

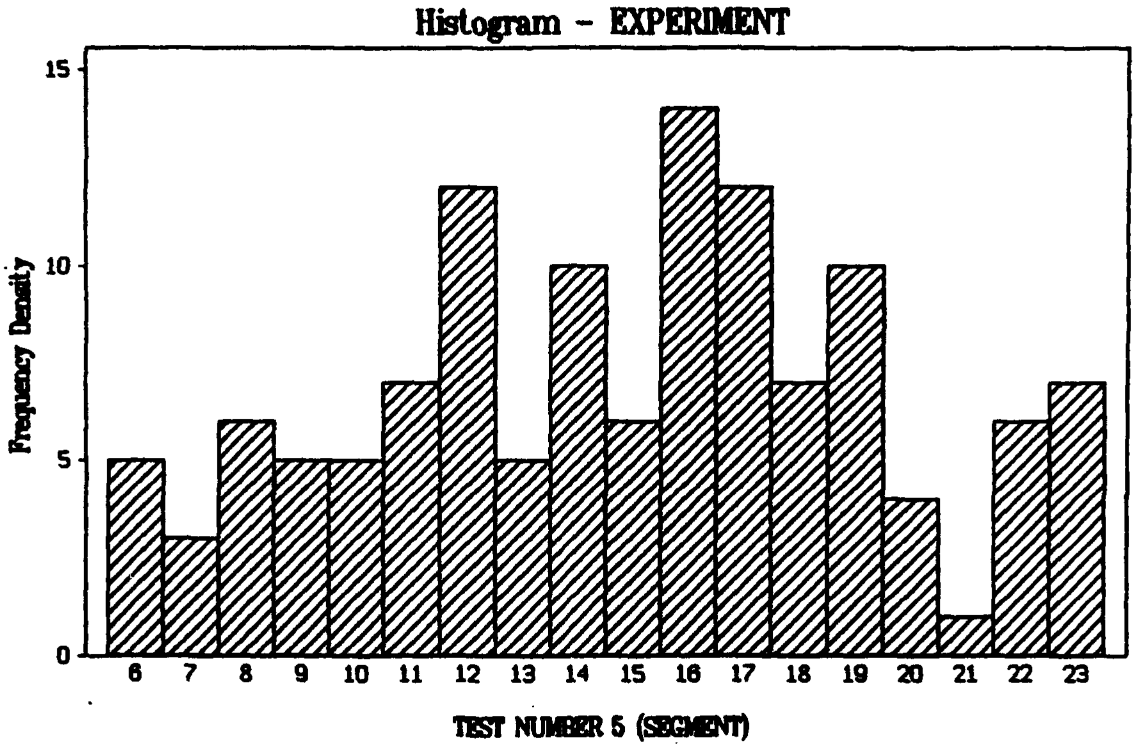

R Chart - EXPERIMENT
36
27
18
9
0
35.616
16.845
0.0000
1
9
17
25
TEST NUMBER 4 (SEGMENTS)
sigma 7.2421


X Bar Chart - EXPERIMENT
29
24
19
14
9
28.973
19.256
9.5405
1
9
17
25
TEST NUMBER 4 (SEGMENT)
sigma 7.2421 E(R bar) 16.845


Histogram - EXPERIMENT
Frequency Density
0
5
10
15
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
TEST NUMBER 4 (SEGMENT)

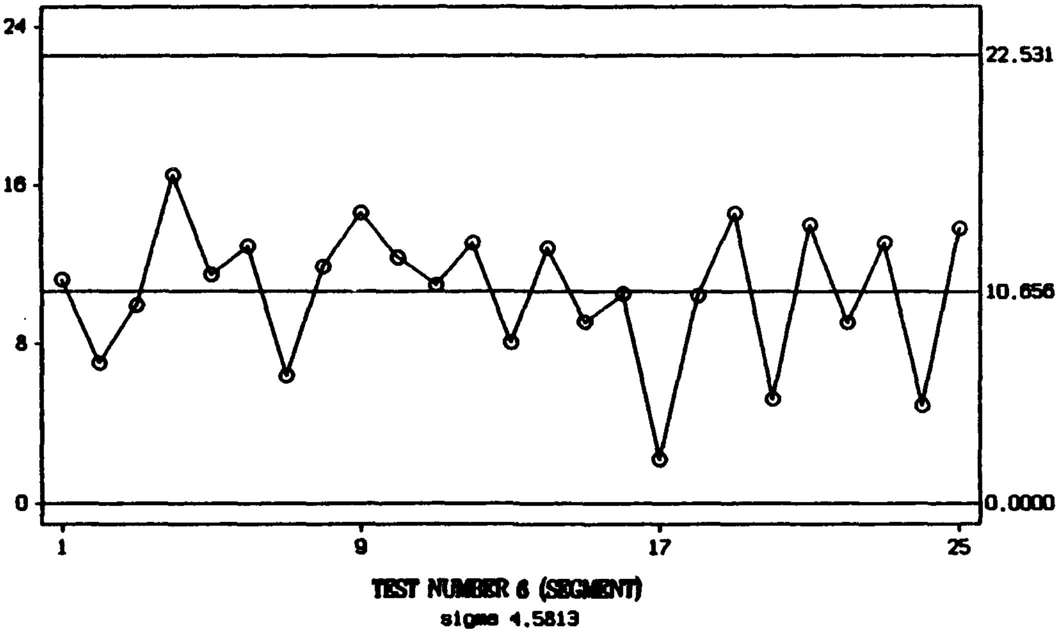

R Chart - EXPERIMENT
24
16
8
0
22.410
10.599
0.0000
1
9
17
25
TEST NUMBER 5 (SEGMENTS)
sigma 4.5568


X Bar Chart - EXPERIMENT
23
18
13
8
21.392
15.278
9.1647
1
9
17
25
TEST NUMBER 5
sigma 4.5568 E(R bar) 10.599

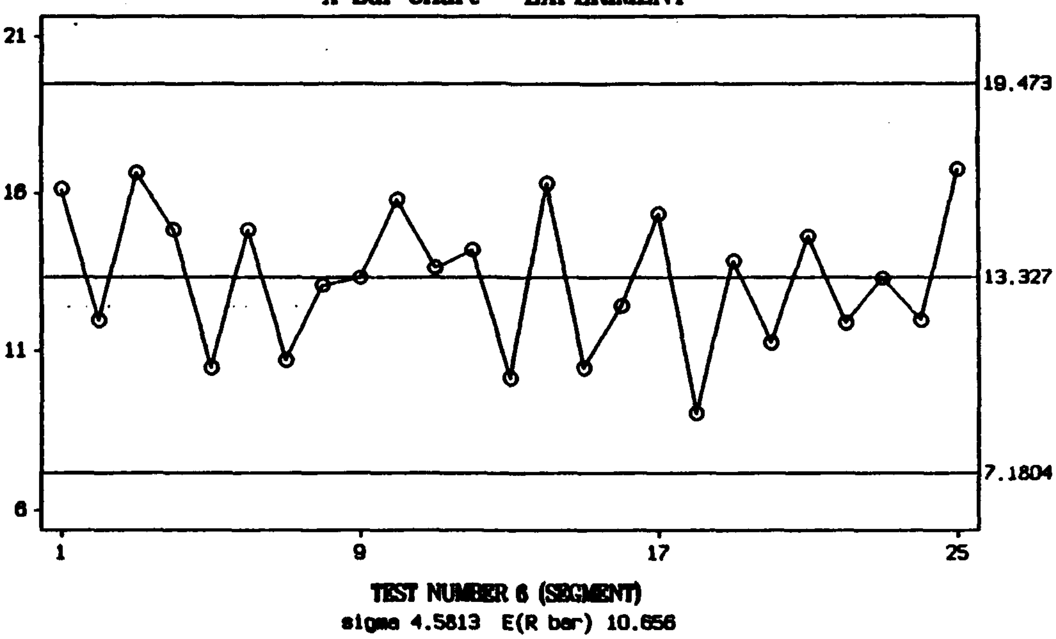


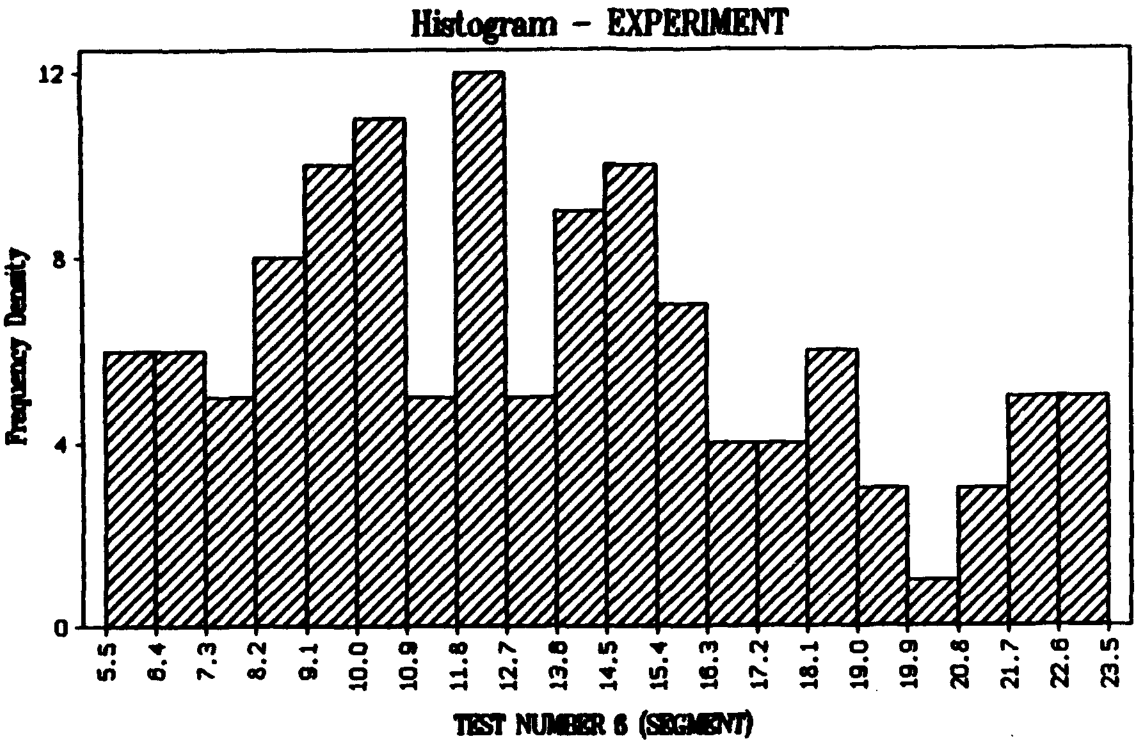
Histogram - EXPERIMENT
15
10
5
0
Frequency Density
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
TEST NUMBER 5 (SEGMENT)

R Chart - EXPERIMENT

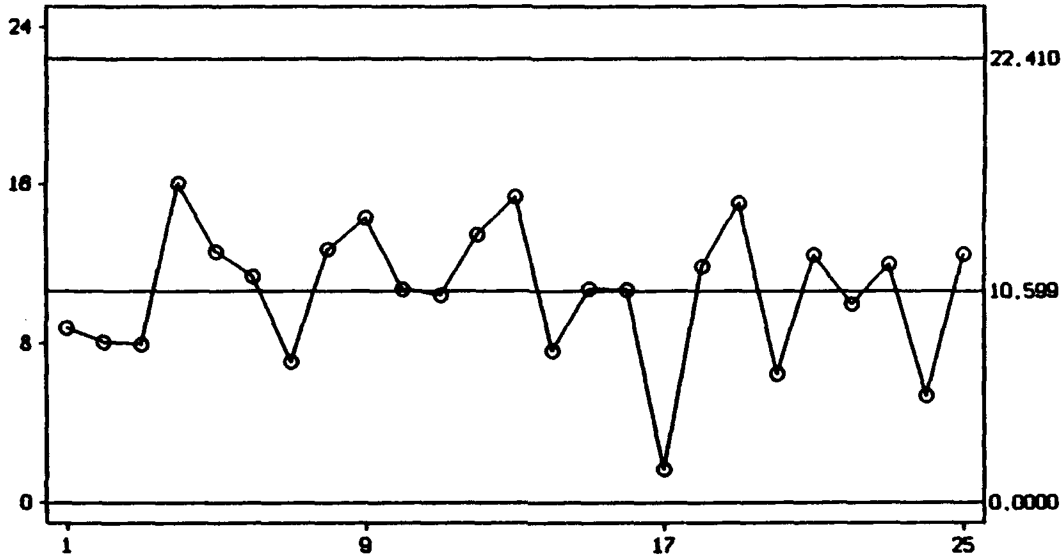


X Bar Chart - EXPERIMENT



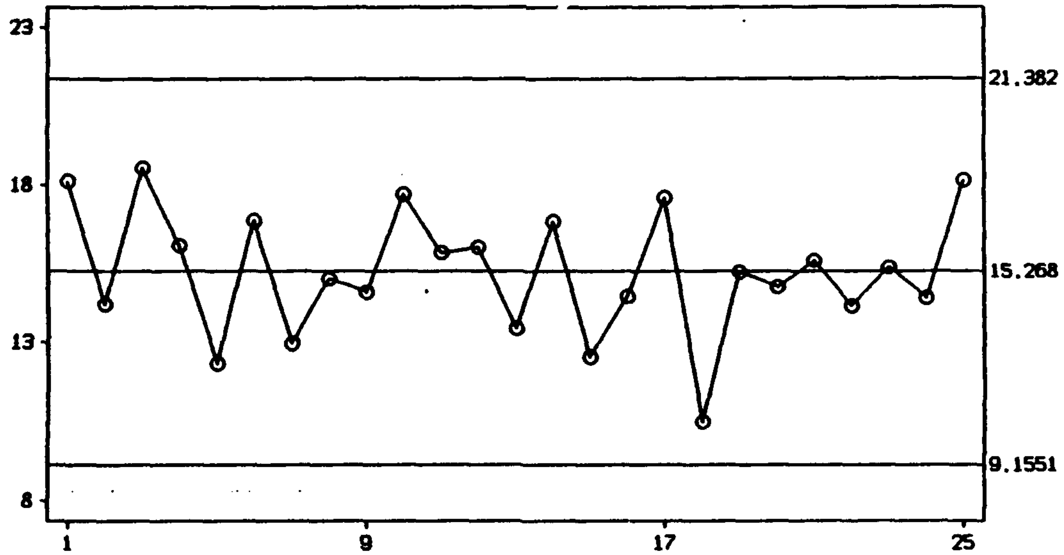

Histogram - EXPERIMENT
Frequency Density
12
8
4
0
5.5
6.4
7.3
8.2
9.1
10.0
10.9
11.8
12.7
13.6
14.5
15.4
16.3
17.2
18.1
19.0
19.9
20.8
21.7
22.6
23.5
TEST NUMBER 6 (SEGMENT)

R Chart - EXPERIMENT

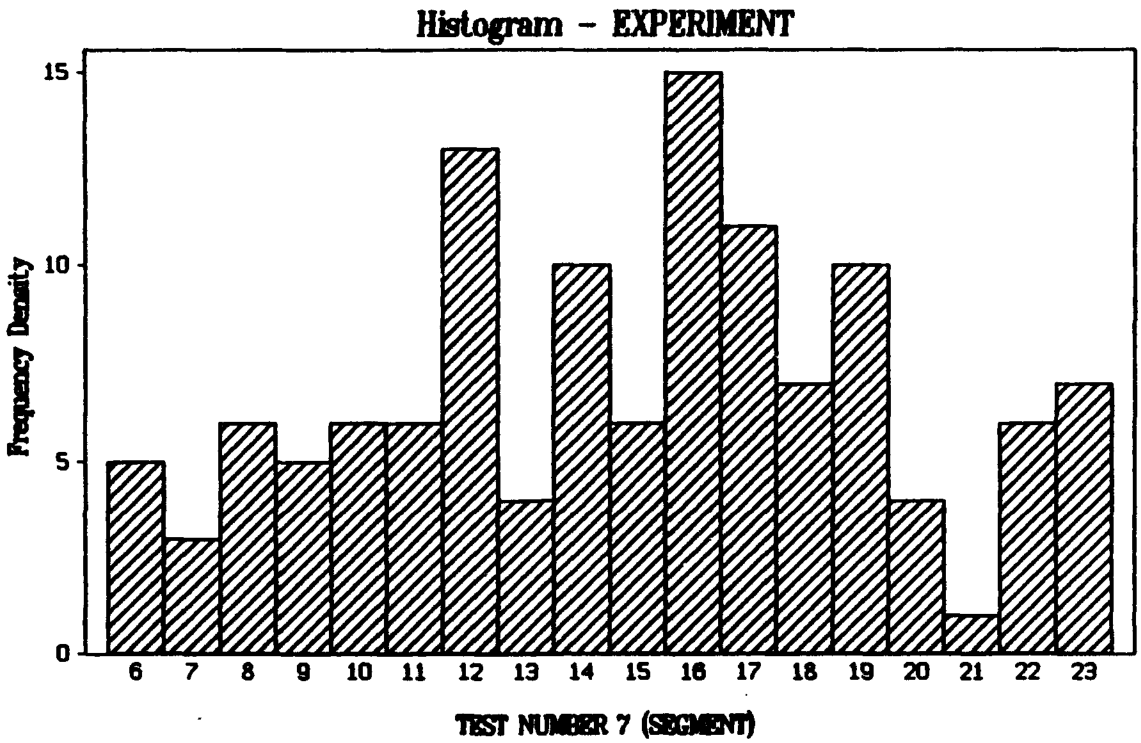


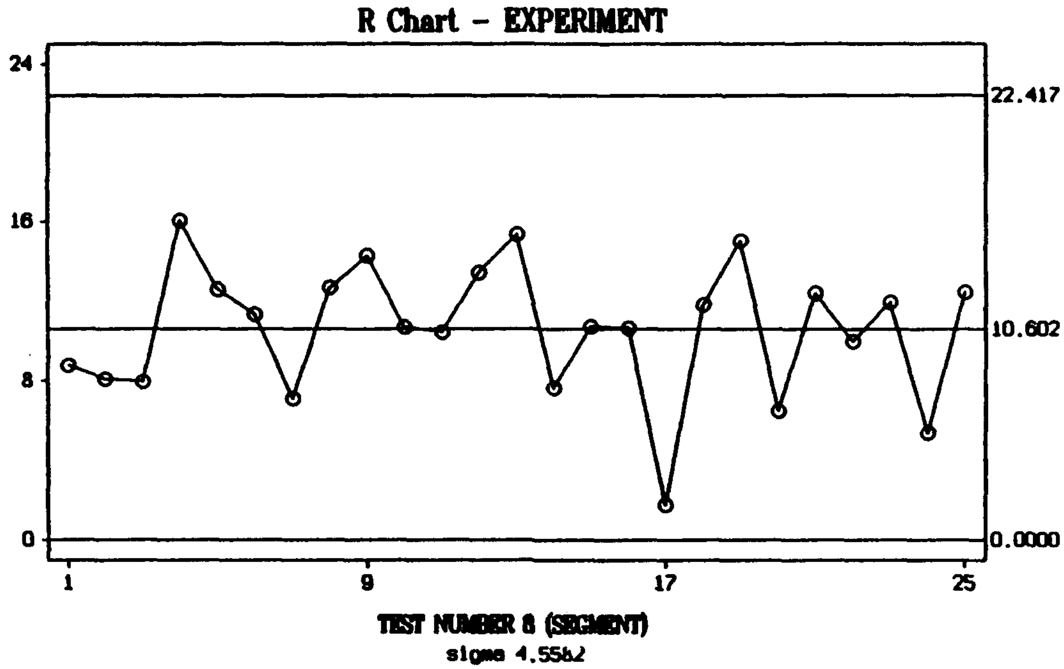
TEST NUMBER 7 (SEGMENT)
sigma 4.5567

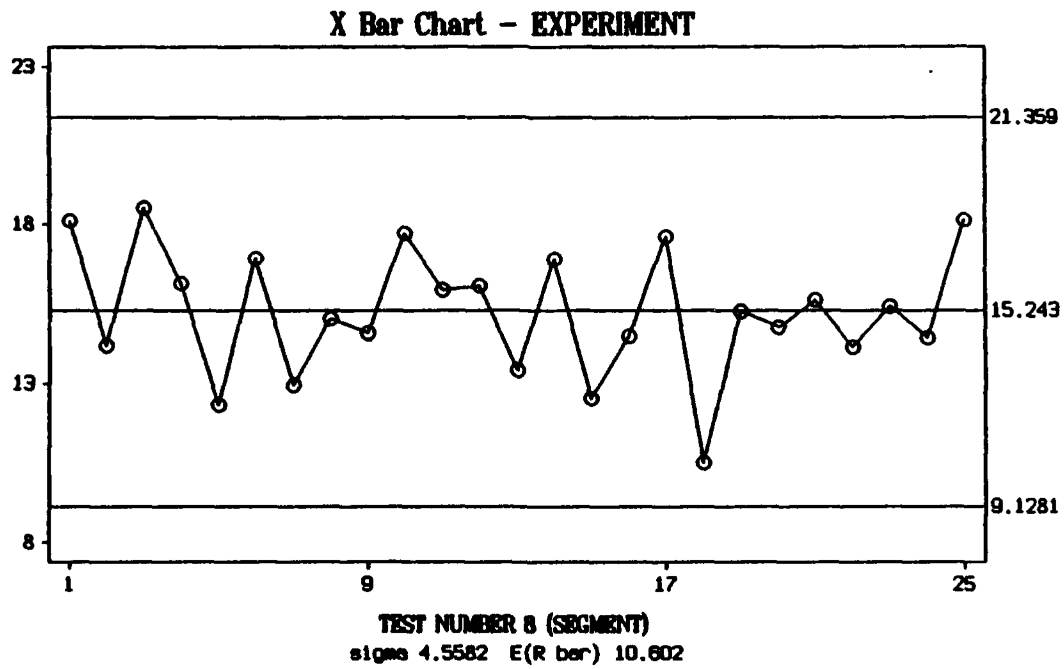
X Bar Chart - EXPERIMENT

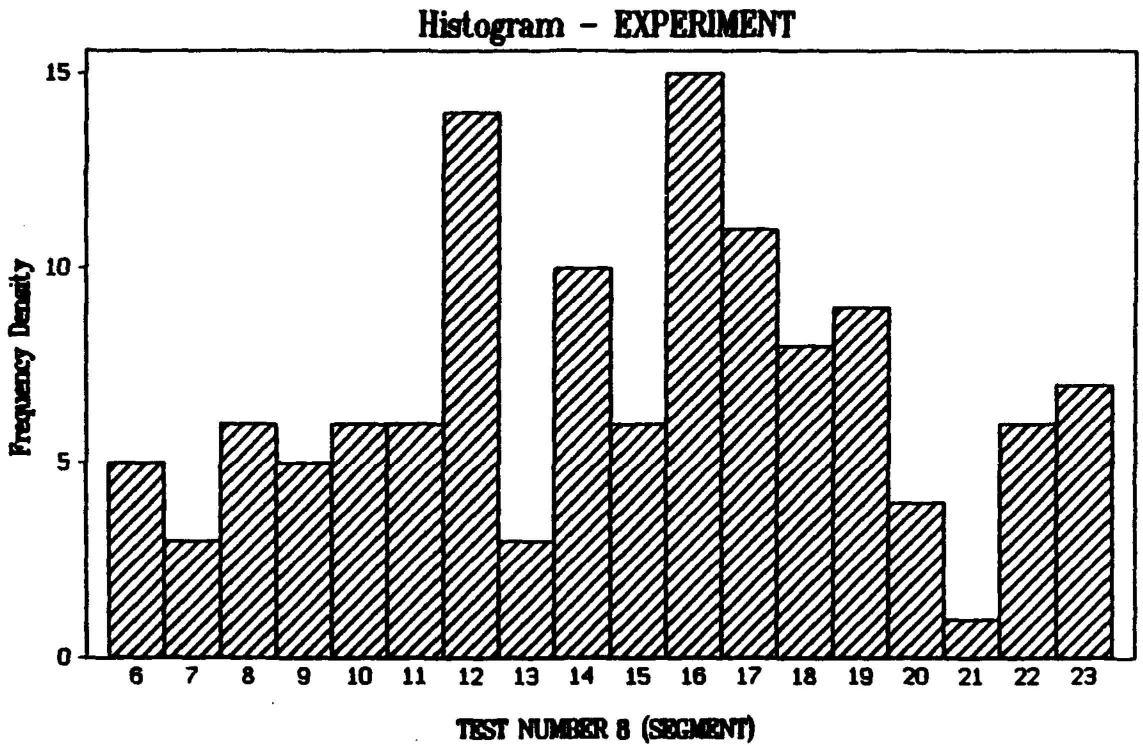


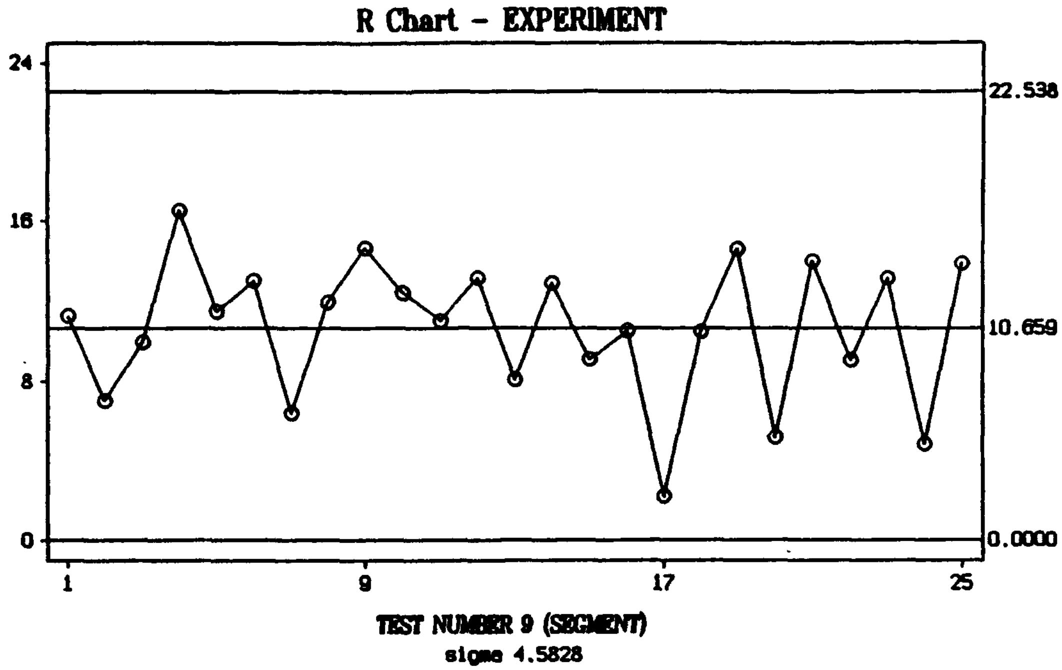
TEST NUMBER 7 (SEGMENT)
sigma 4.5567 E(R bar) 10.599

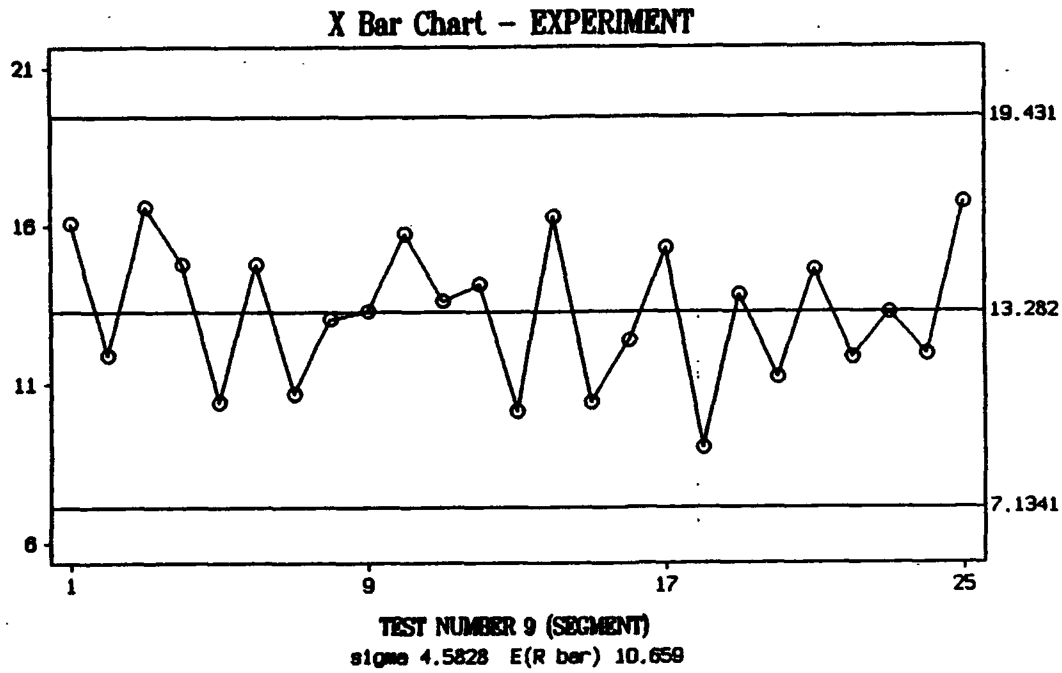

Histogram - EXPERIMENT
Frequency Density
15
10
5
0
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
TEST NUMBER 7 (SEGMENT)


R Chart - EXPERIMENT
24
16
8
0
22.417
10.602
0.0000
1
9
17
25
TEST NUMBER 8 (SEGMENT)
sigma 4.5582

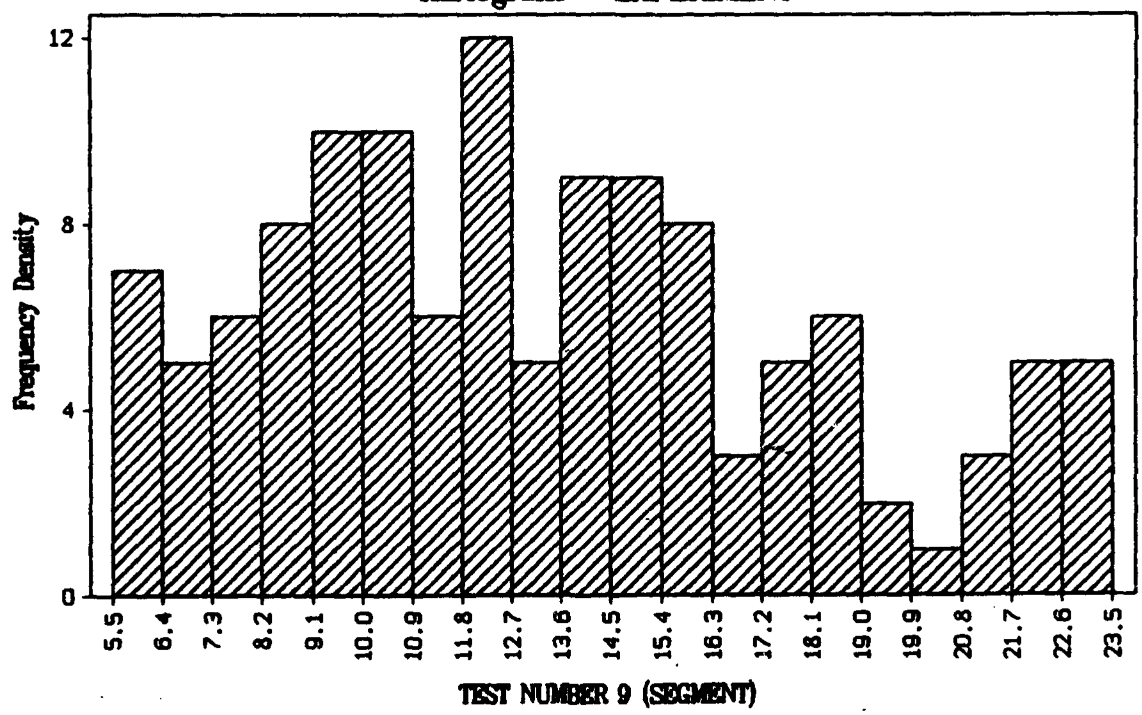

X Bar Chart - EXPERIMENT
23
18
13
8
21.359
15.243
9.1281
1
9
17
25
TEST NUMBER 8 (SEGMENT)
sigma 4.5582 E(R bar) 10.602


Histogram - EXPERIMENT
Frequency Density
15
10
5
0
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
TEST NUMBER 8 (SEGMENT)

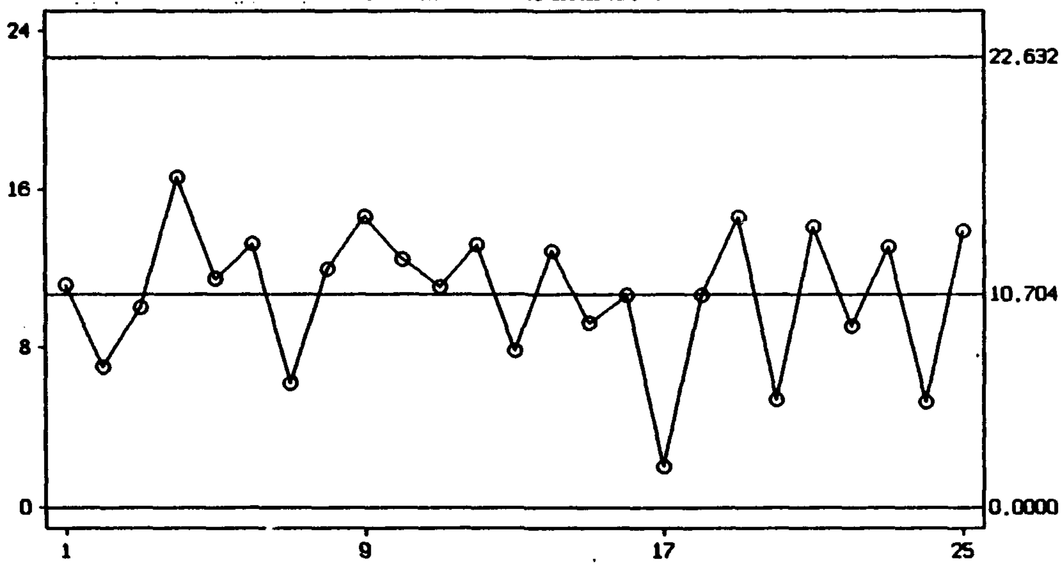

R Chart - EXPERIMENT
24
16
8
0
22.538
10.659
0.0000
1
9
17
25
TEST NUMBER 9 (SEGMENT)
sigma 4.5828


X Bar Chart - EXPERIMENT
21
16
11
6
19.431
13.282
7.1341
1
9
17
25
TEST NUMBER 9 (SEGMENT)
sigma 4.5828 E(R bar) 10.659

Histogram - EXPERIMENT

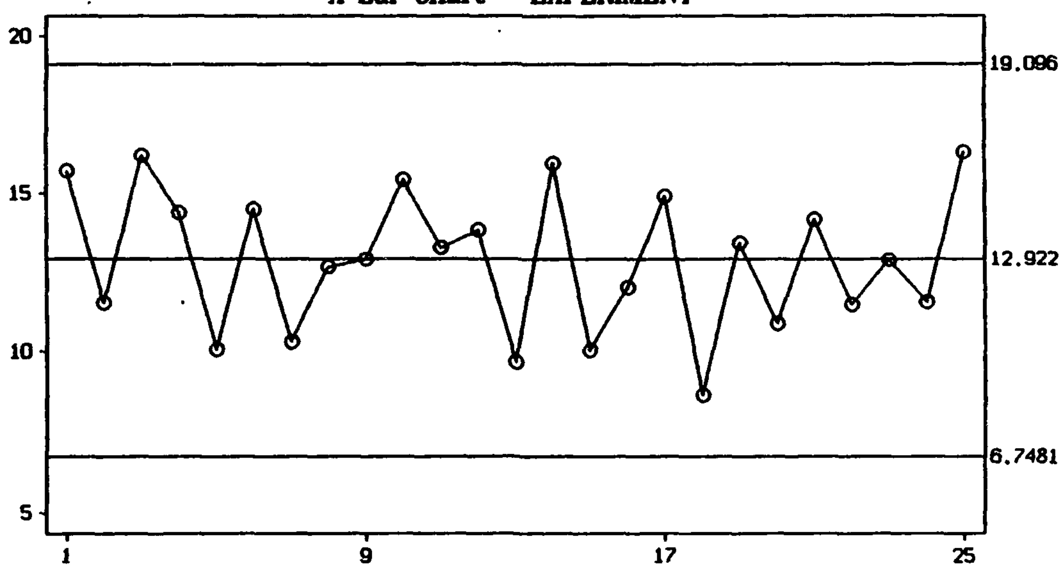


R Chart - EXPERIMENT



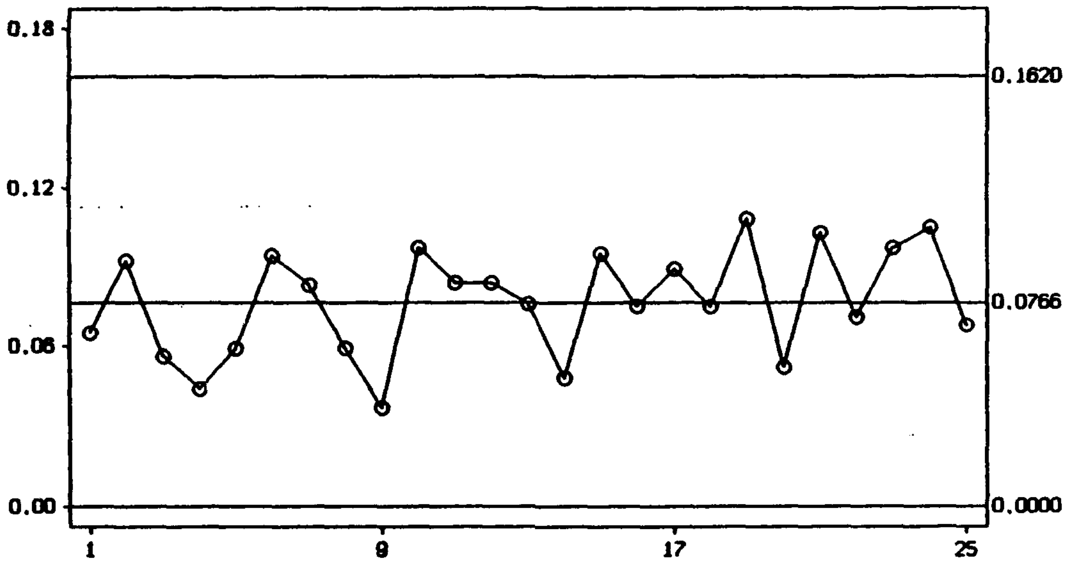
TEST NUMBER 9 (MAINT-TO-SUP)
sigma 4.6020

X Bar Chart - EXPERIMENT



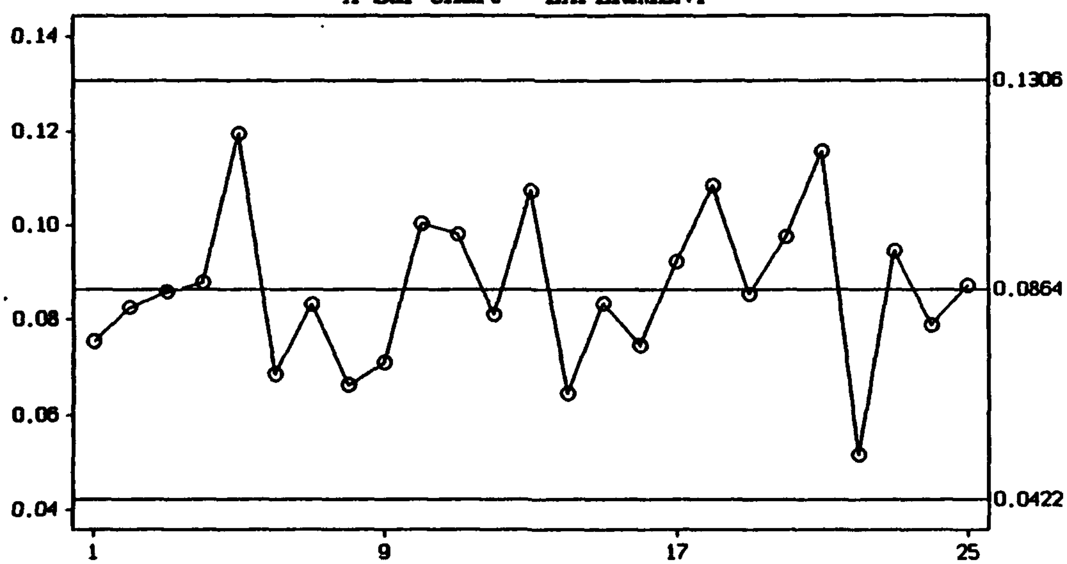
TEST NUMBER 9 (MAINT-TO-SUP)
sigma 4.6020 E(R bar) 10.704

R Chart - EXPERIMENT

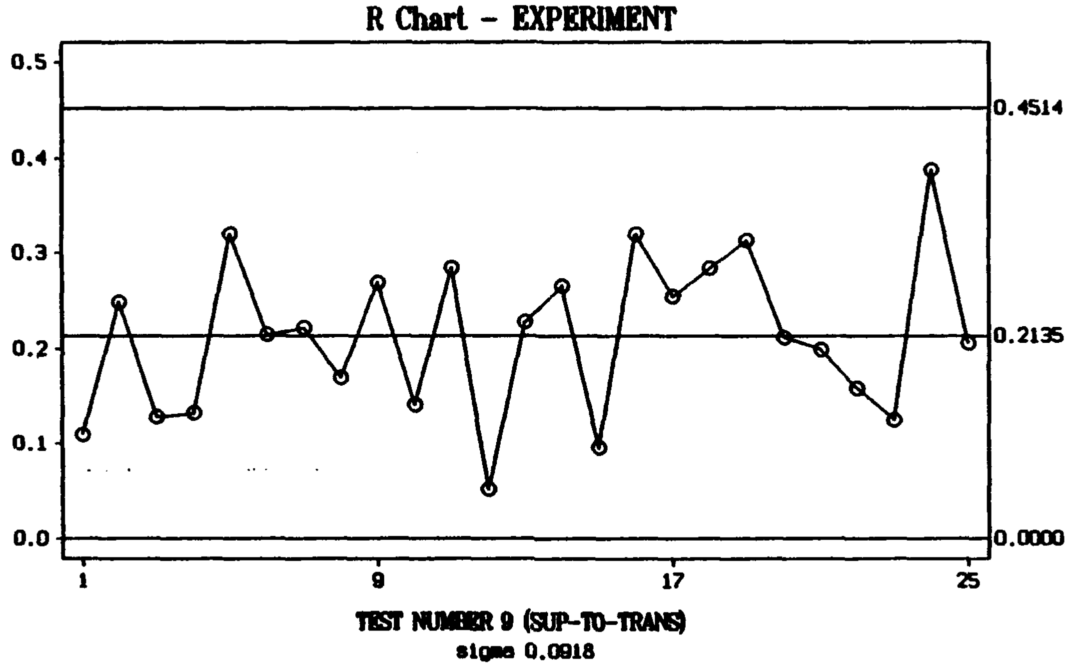


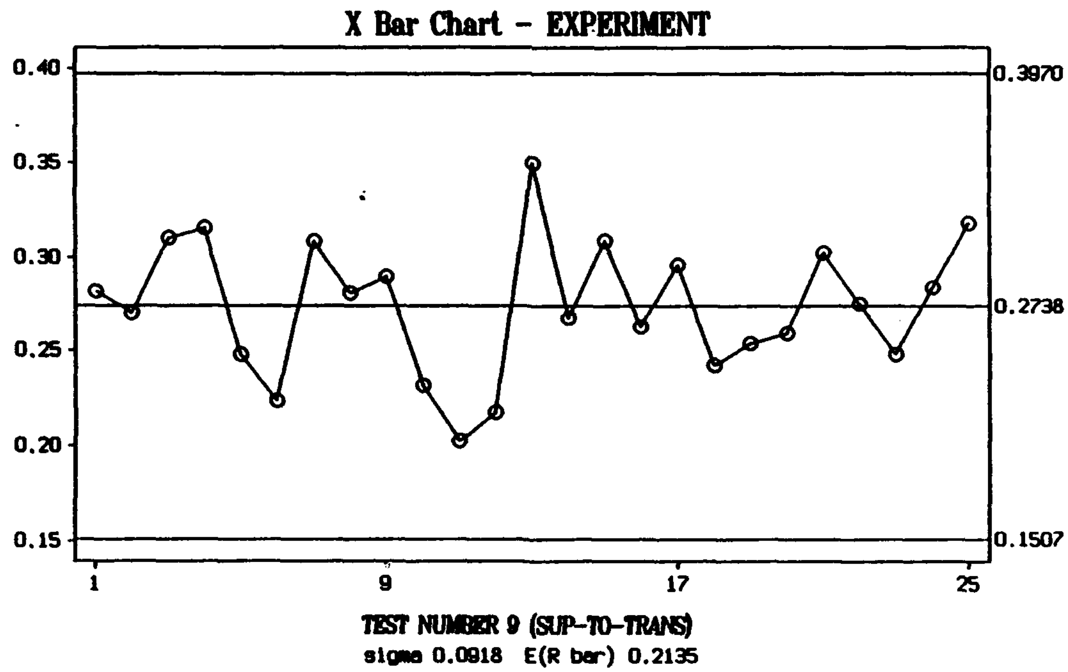
TEST NUMBER 9 (SUPPLY)
sigma 0.0329

X Bar Chart - EXPERIMENT

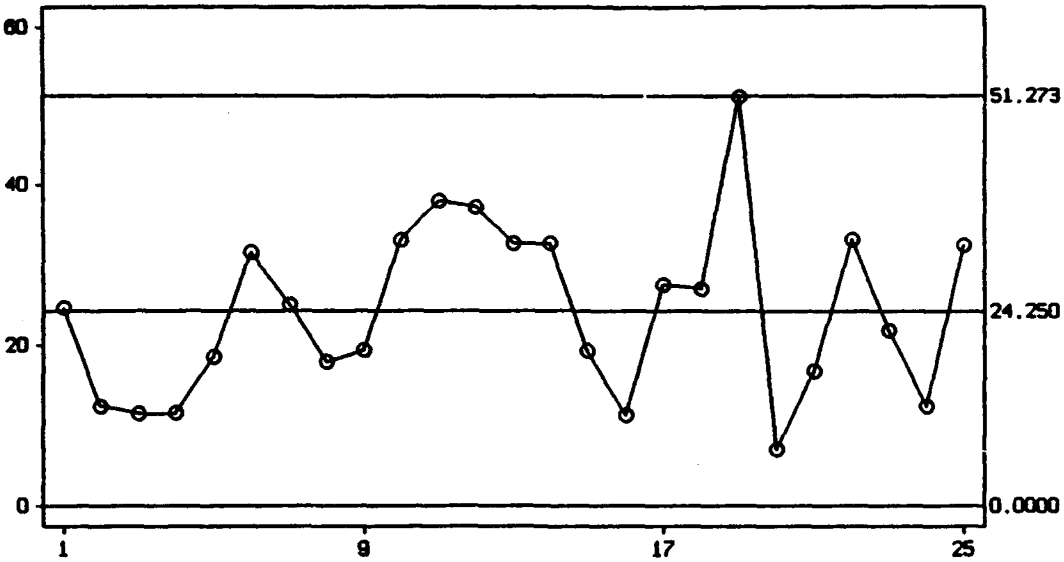


TEST NUMBER 9 (SUPPLY)
sigma 0.0329 E(R bar) 0.0766


R Chart - EXPERIMENT
0.5
0.4
0.3
0.2
0.1
0.0
0.4514
0.2135
0.0000
1
9
17
25
TEST NUMBER 9 (SUP-TO-TRANS)
sigma 0.0918


X Bar Chart - EXPERIMENT
0.40
0.35
0.30
0.25
0.20
0.15
0.3970
0.2738
0.1507
1
9
17
25
TEST NUMBER 9 (SUP-TO-TRANS)
sigma 0.0918 E(R bar) 0.2135

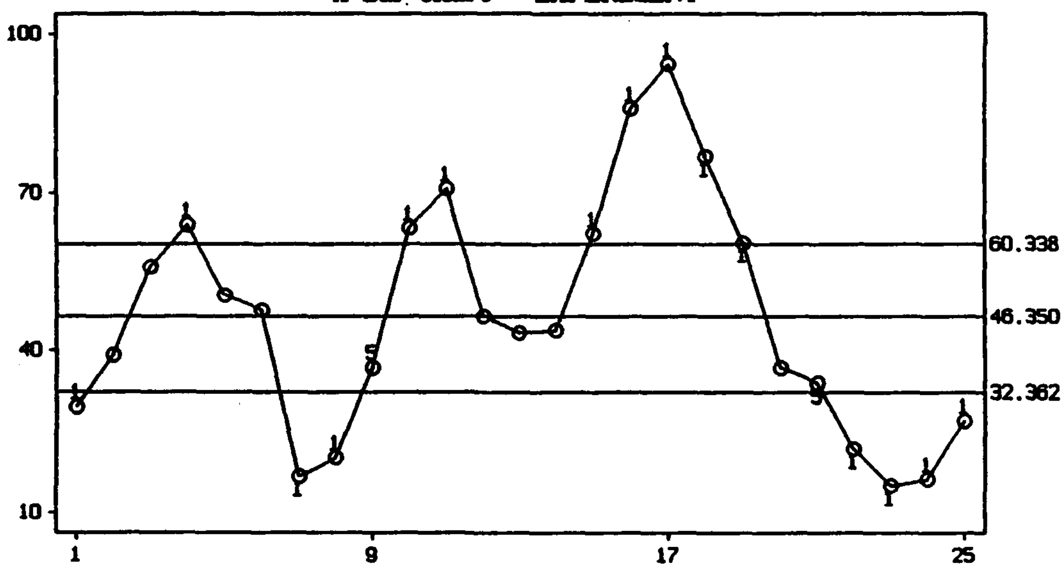
R Chart - EXPERIMENT



TEST NUMBER 10 (SEGMENT)

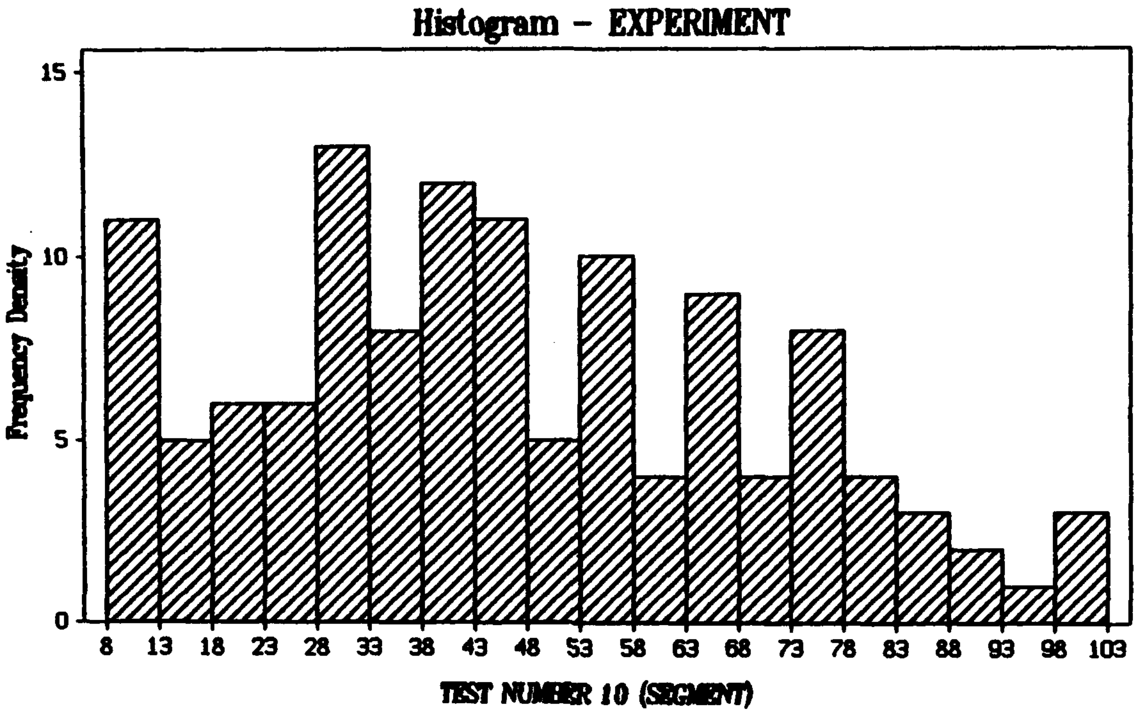
sigma 10.425

X Bar Chart - EXPERIMENT

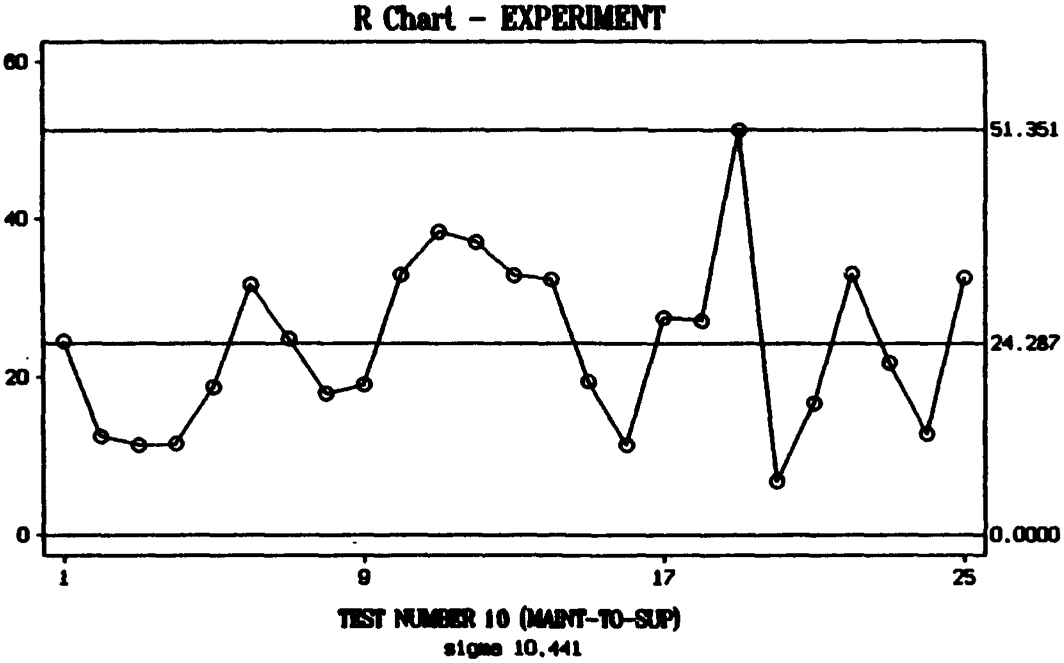


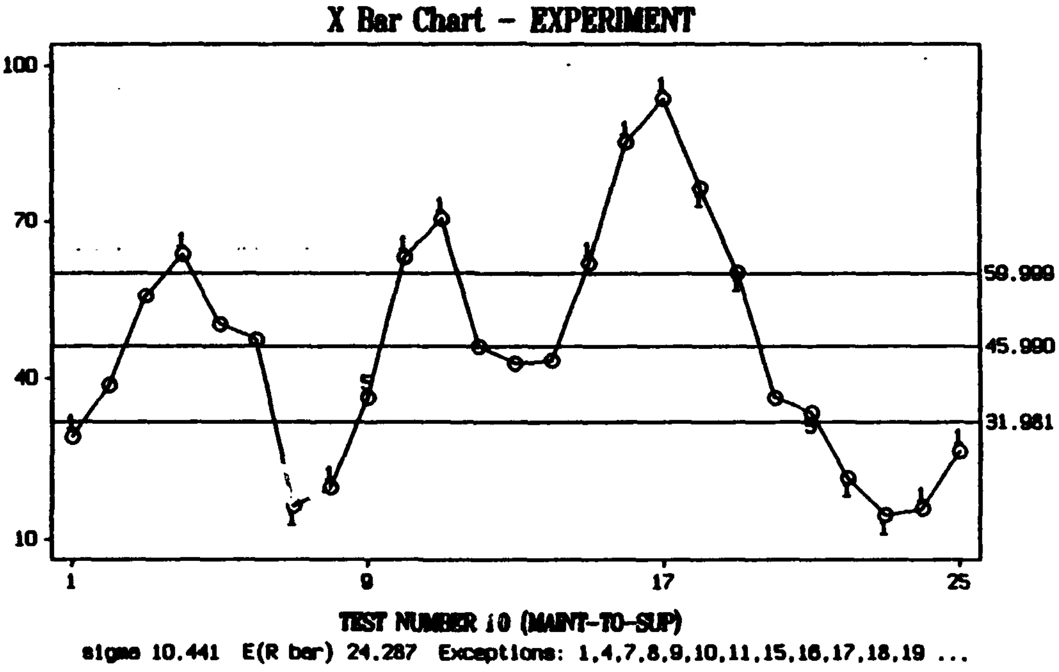
TEST NUMBER 10 (SEGMENT)

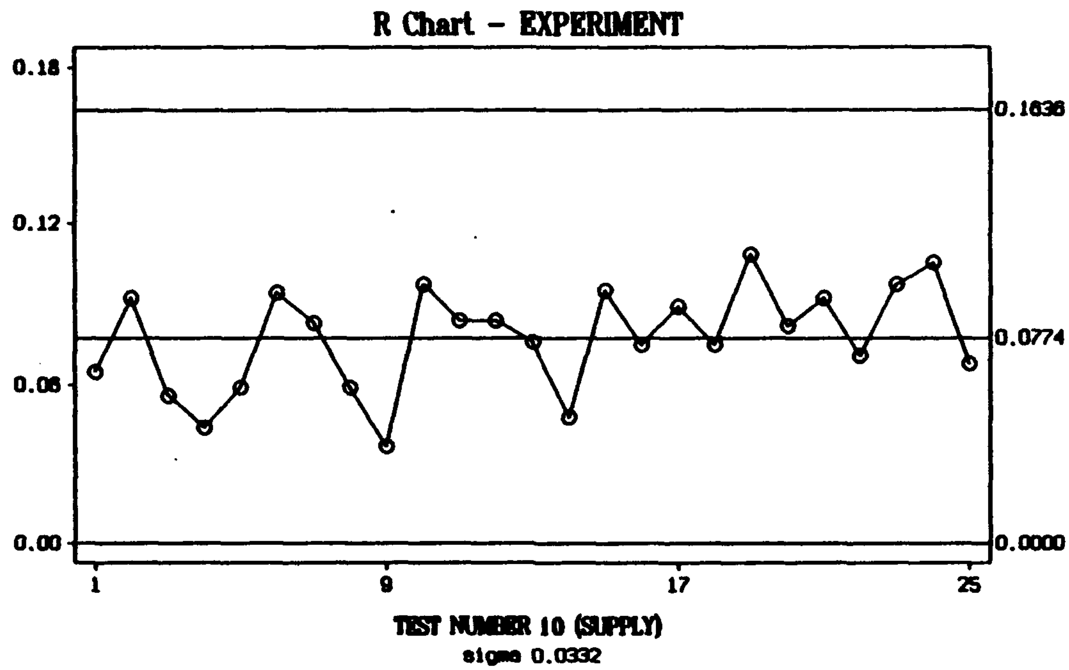
sigma 10.425 E(R bar) 24.250 Exceptions: 1,4,7,8,9,10,11,15,16,17,18,19 ...

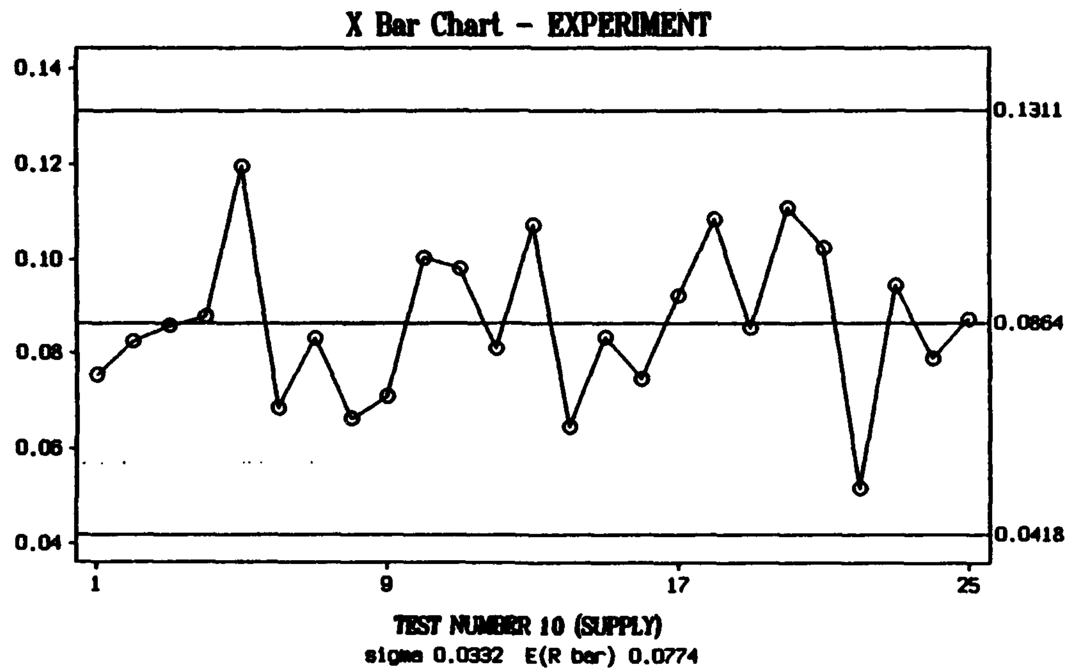


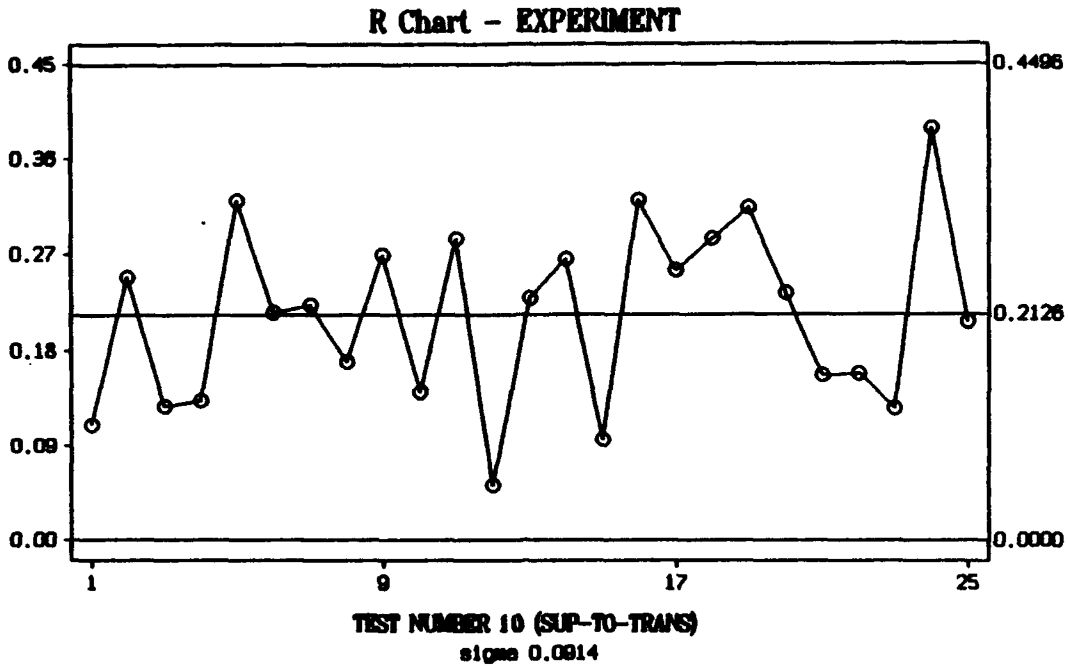
MAINTENANCE CAPACITY DECREASED TO 1

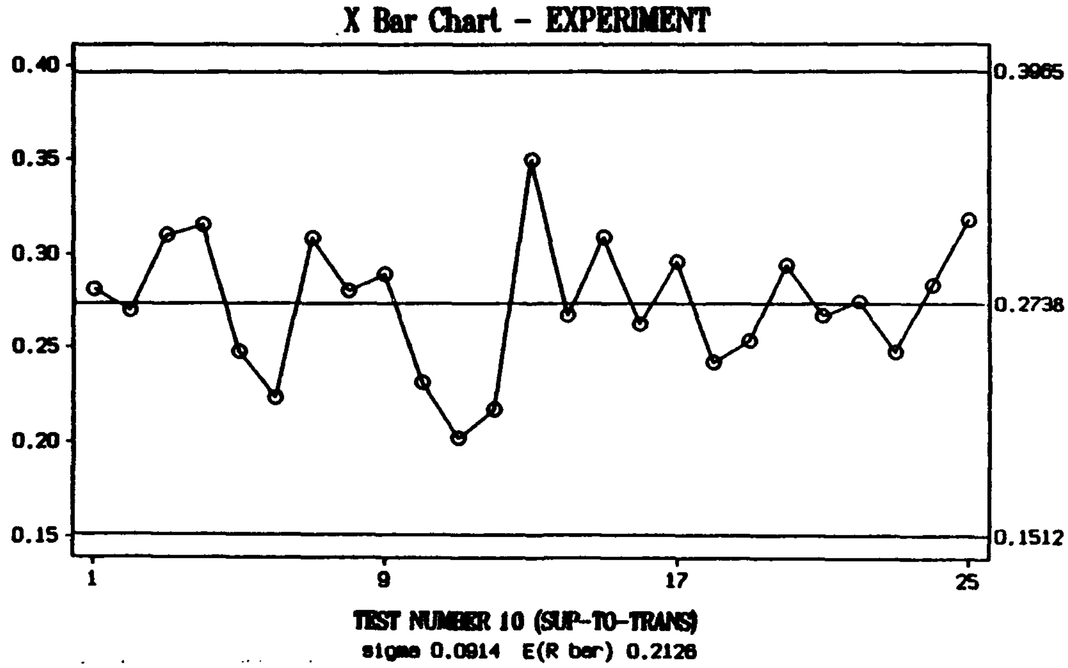

R Chart - EXPERIMENT
60
40
20
0
51.351
24.287
0.0000
1
9
17
25
TEST NUMBER 10 (MAINT-TO-SUP)
sigma 10.441


X Bar Chart - EXPERIMENT
100
70
40
10
59.998
45.990
31.981
1
9
17
25
TEST NUMBER 10 (MAINT-TO-SUP)
sigma 10.441 E(R bar) 24.287 Exceptions: 1,4,7,8,9,10,11,15,16,17,18,19 ...

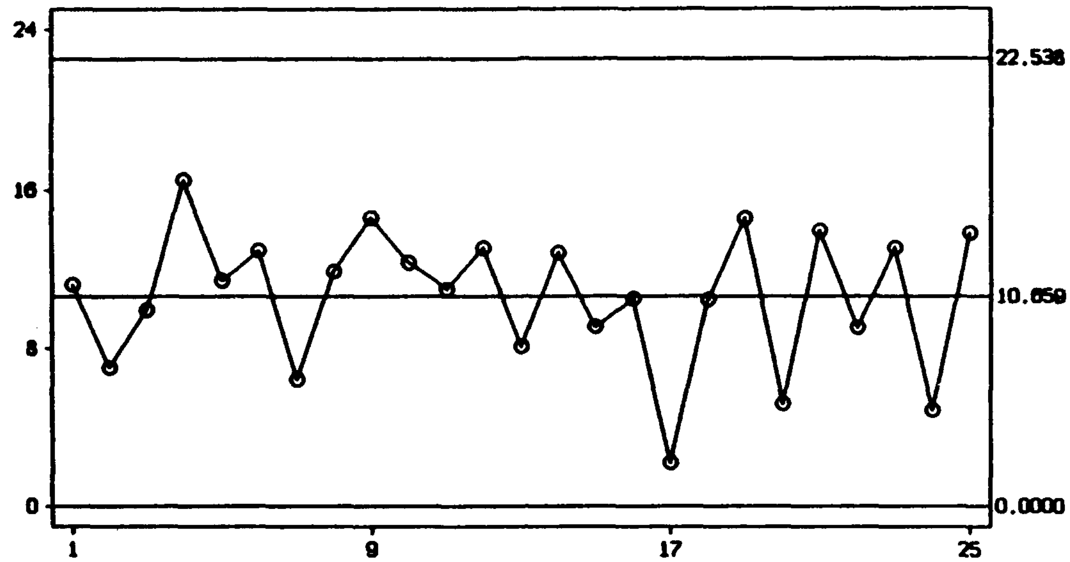

R Chart - EXPERIMENT
0.18
0.12
0.06
0.00
0.1636
0.0774
0.0000
1
9
17
25
TEST NUMBER 10 (SUPPLY)
sigma 0.0332


X Bar Chart - EXPERIMENT
0.14
0.12
0.10
0.08
0.06
0.04
0.1311
0.0864
0.0418
1
9
17
25
TEST NUMBER 10 (SUPPLY)
sigma 0.0332 E(R bar) 0.0774


R Chart - EXPERIMENT
0.45
0.36
0.27
0.18
0.09
0.00
0.4496
0.2126
0.0000
1
9
17
25
TEST NUMBER 10 (SUP-TO-TRANS)
sigma 0.0914

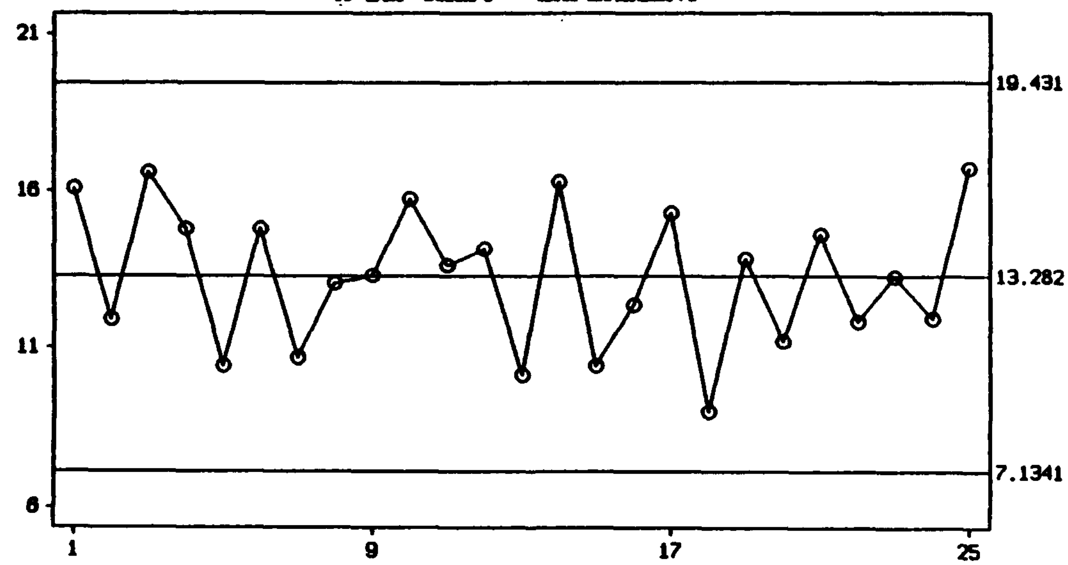

X Bar Chart - EXPERIMENT
0.40
0.35
0.30
0.25
0.20
0.15
0.3965
0.2738
0.1512
1
9
17
25
TEST NUMBER 10 (SUP-TO-TRANS)
sigma 0.0914 E(R bar) 0.2126

R Chart - EXPERIMENT

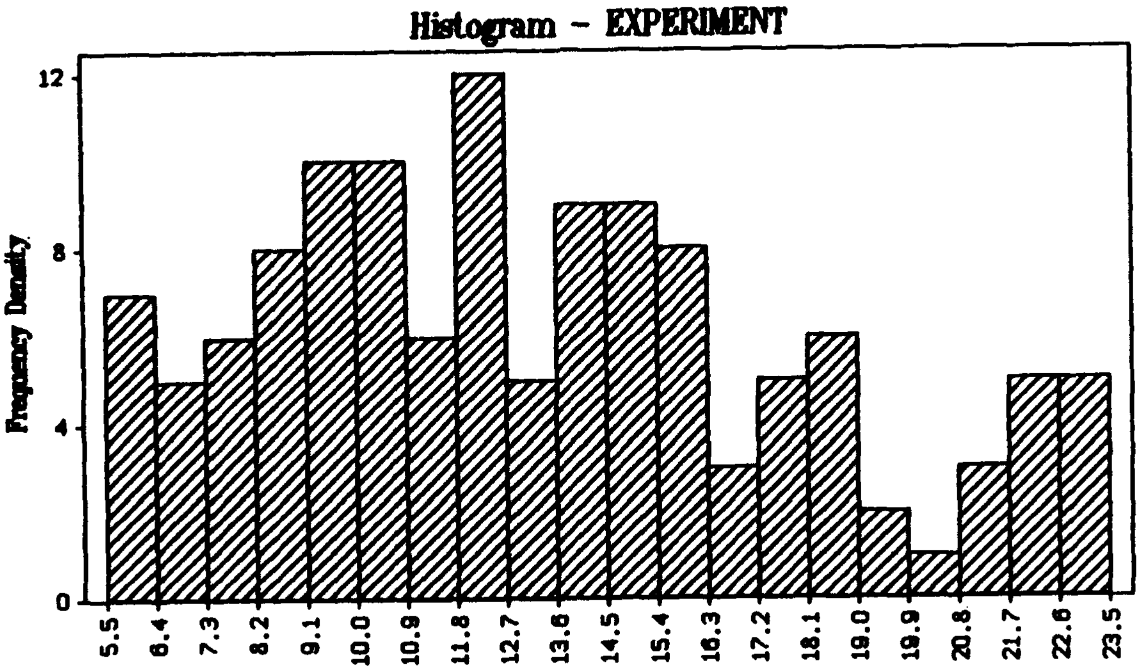


TEST NUMBER 11 (SEGMENT)
sigma 4.5828

X Bar Chart - EXPERIMENT

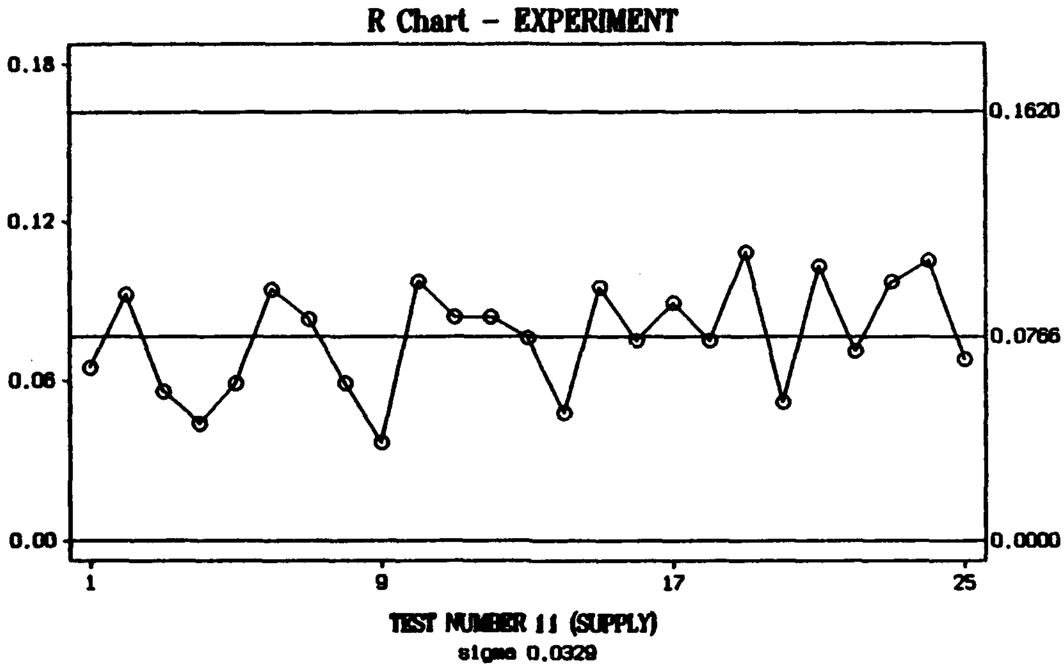


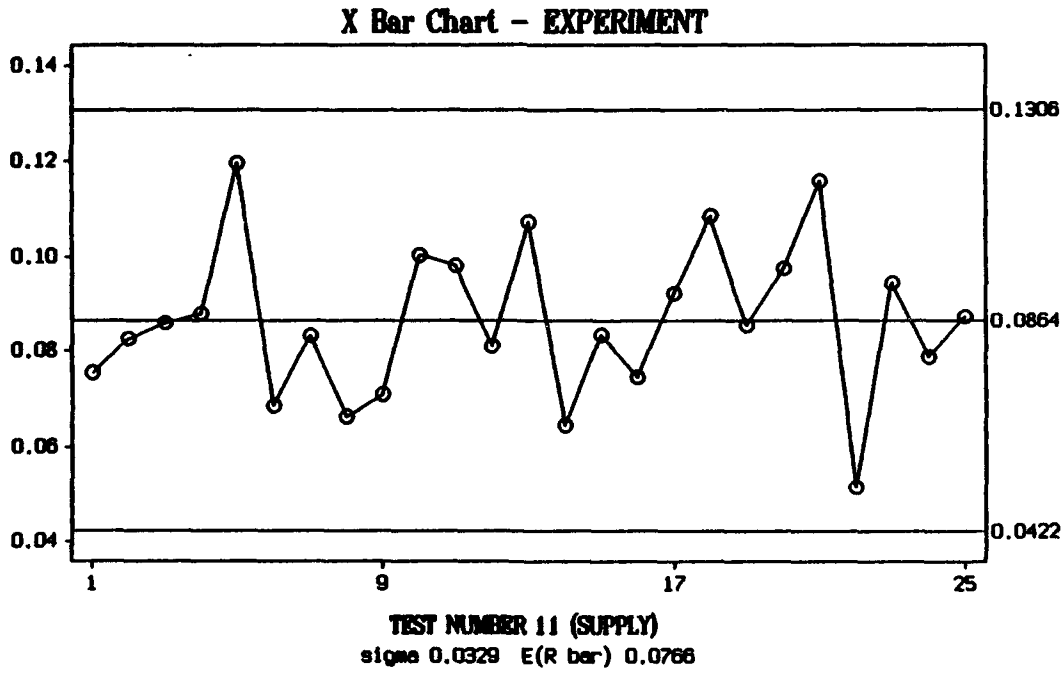
TEST NUMBER 11 (SEGMENT)
sigma 4.5828 E(R bar) 10.659

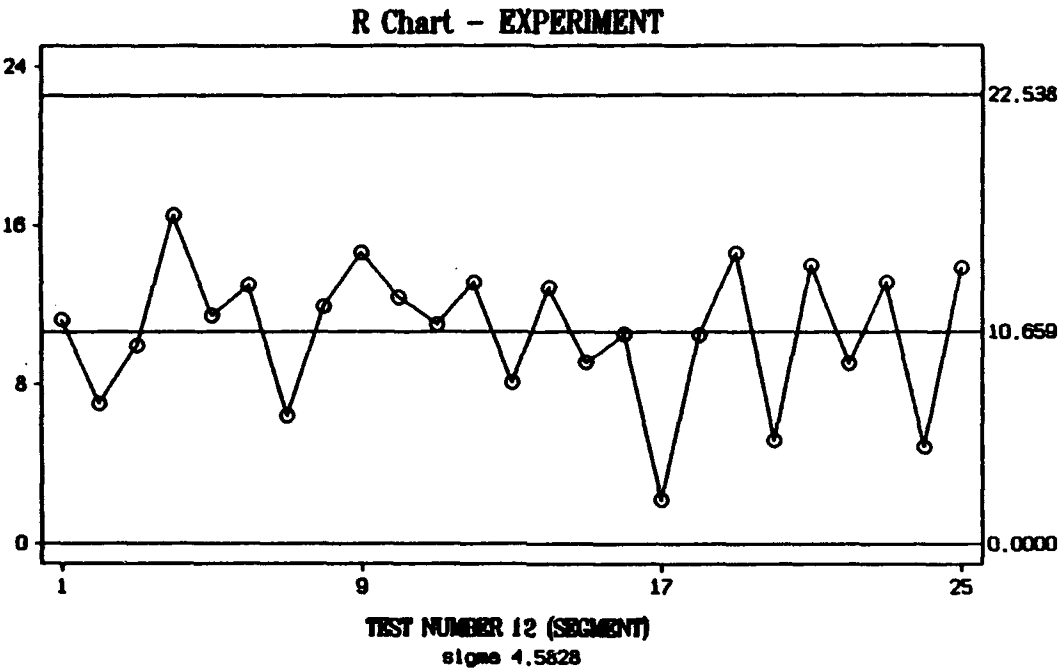


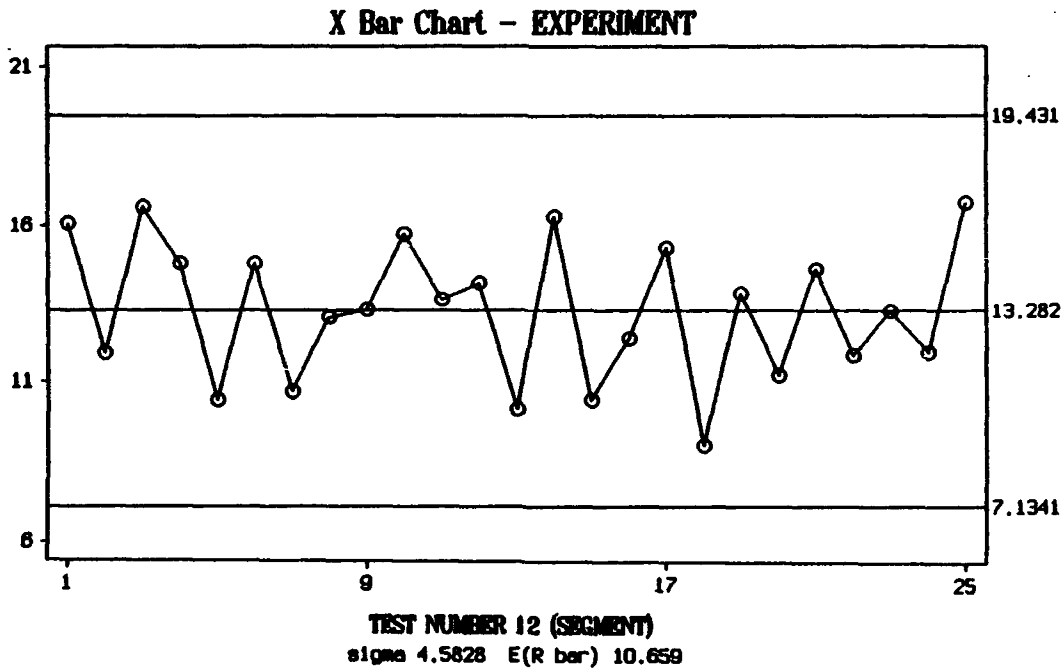
TEST NUMBER 11 (SEGMENT)

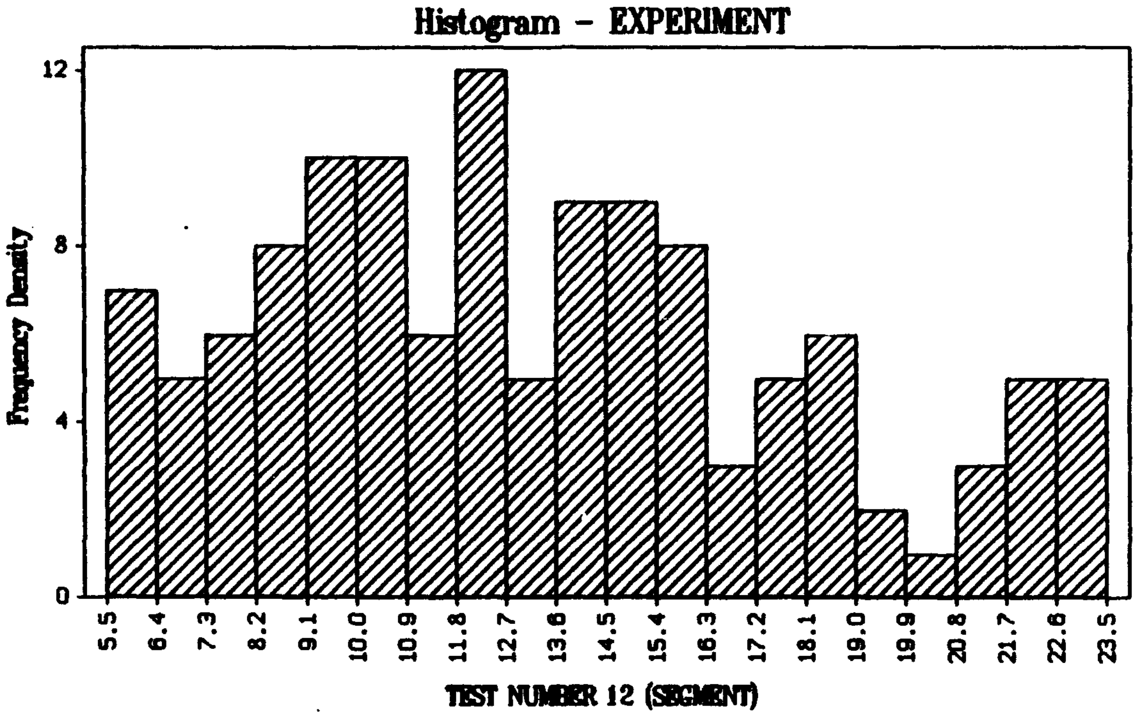
SUPPLY PROCESSING CAPACITY REDUCED FROM 10 TO 2


R Chart - EXPERIMENT
0.18
0.12
0.06
0.00
0.1620
0.0766
0.0000
1
9
17
25
TEST NUMBER 11 (SUPPLY)
sigma 0.0329

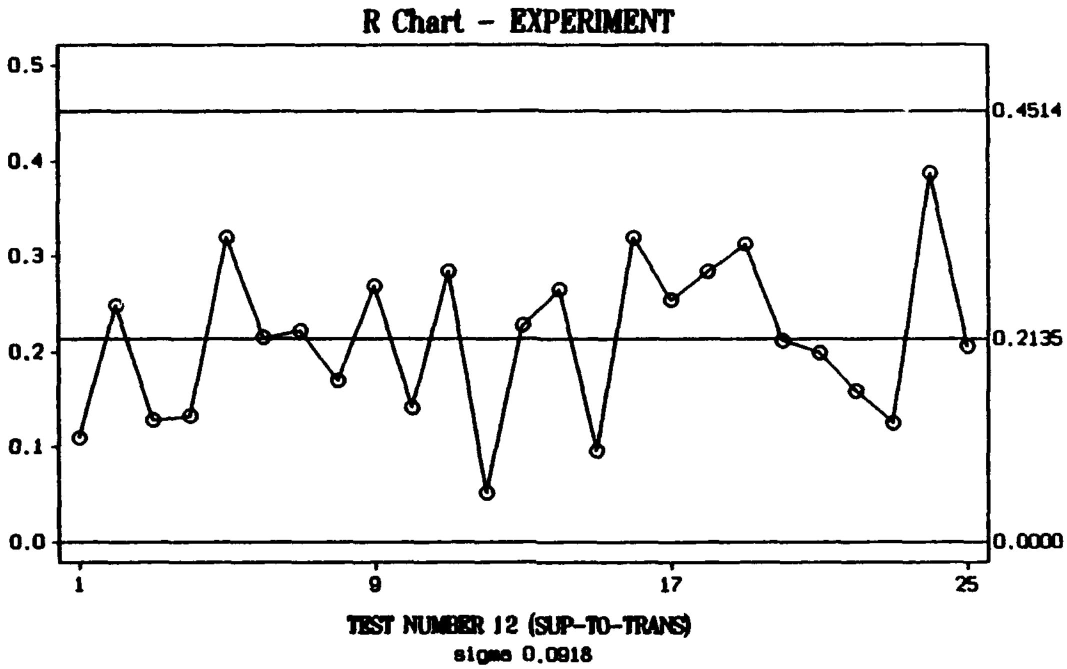

X Bar Chart - EXPERIMENT
0.14
0.12
0.10
0.08
0.06
0.04
0.1306
0.0864
0.0422
1
9
17
25
TEST NUMBER 11 (SUPPLY)
sigma 0.0329 E(R bar) 0.0766


R Chart - EXPERIMENT
24
16
8
0
22.538
10.659
0.0000
1
9
17
25
TEST NUMBER 12 (SEGMENT)
sigma 4.5828

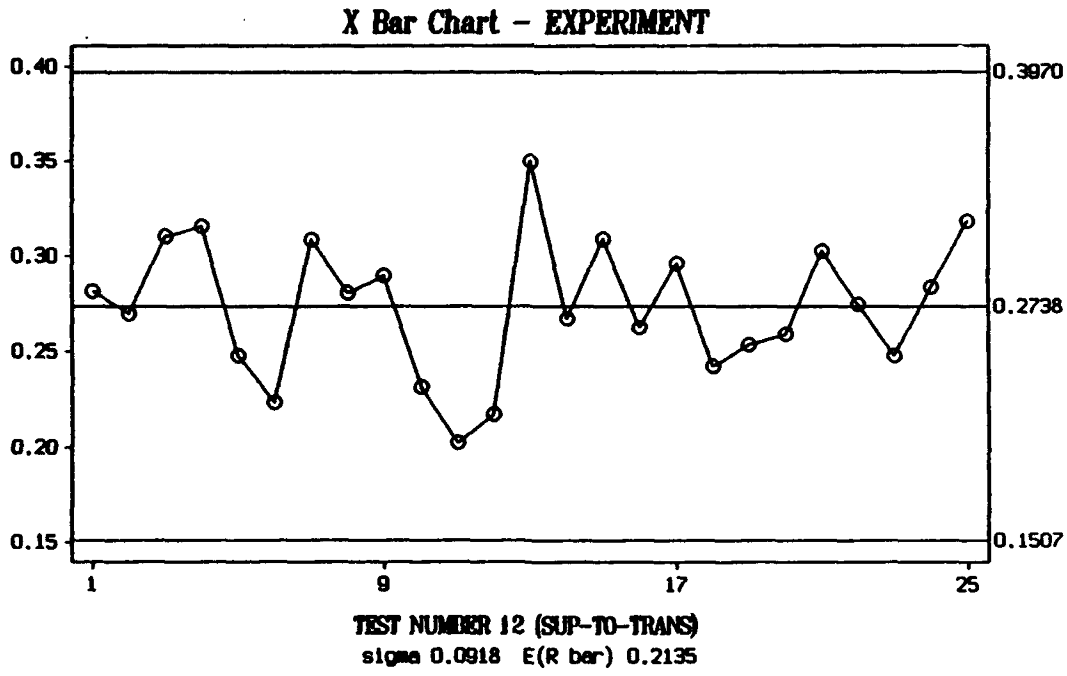

X Bar Chart - EXPERIMENT
21
16
11
6
19.431
13.282
7.1341
1
9
17
25
TEST NUMBER 12 (SEGMENT)
sigma 4.5828 E(R bar) 10.659



SUP-TO-TRANS CAPACITY REDUCED FROM 10 TO 2

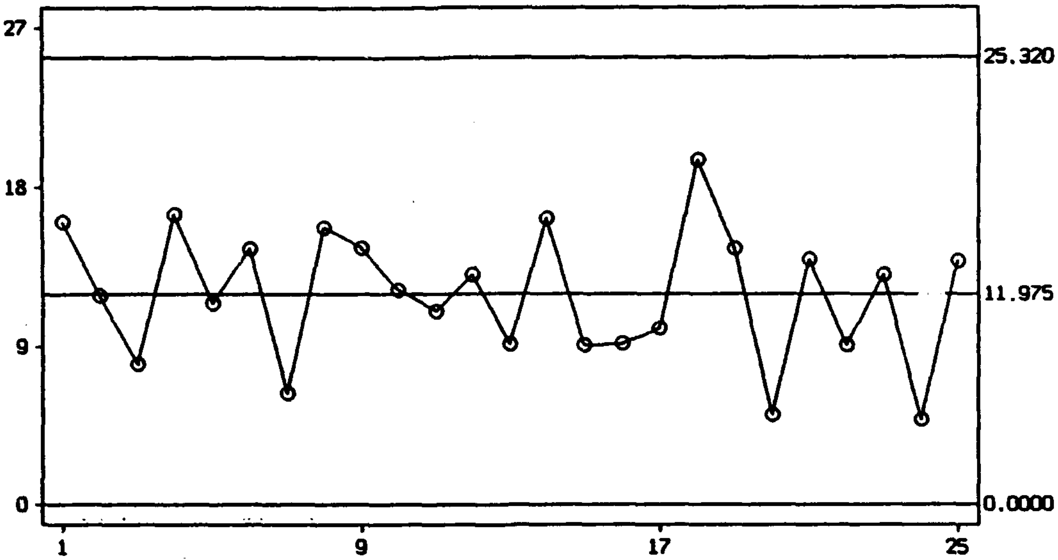


R Chart - EXPERIMENT
0.5
0.4
0.3
0.2
0.1
0.0
0.4514
0.2135
0.0000
1
9
17
25
TEST NUMBER 12 (SUP-TO-TRANS)
sigma 0.0918



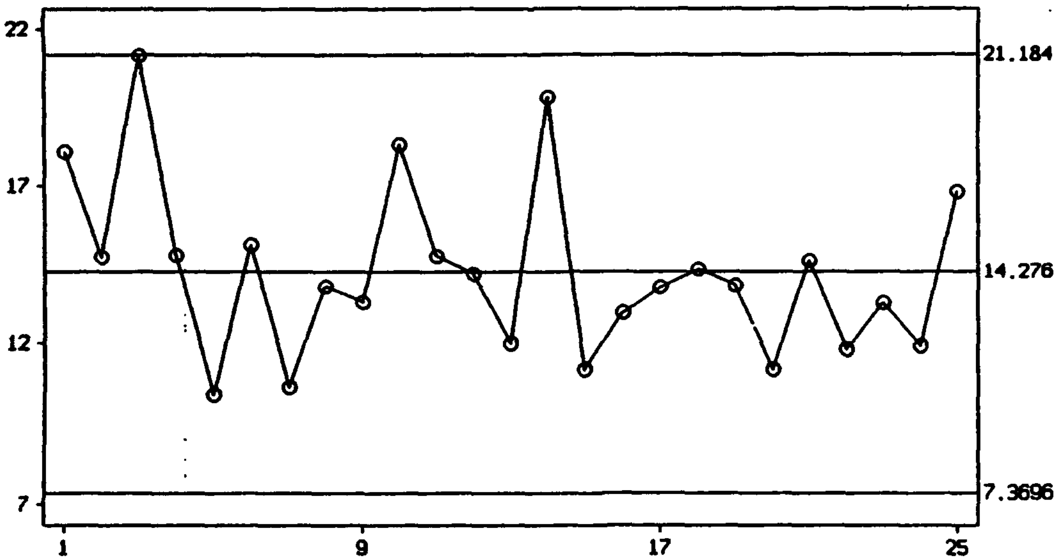
X Bar Chart - EXPERIMENT
0.40
0.35
0.30
0.25
0.20
0.15
0.3970
0.2738
0.1507
1
9
17
25
TEST NUMBER 12 (SUP-TO-TRANS)
sigma 0.0918 E(R bar) 0.2135

R Chart - EXPERIMENT

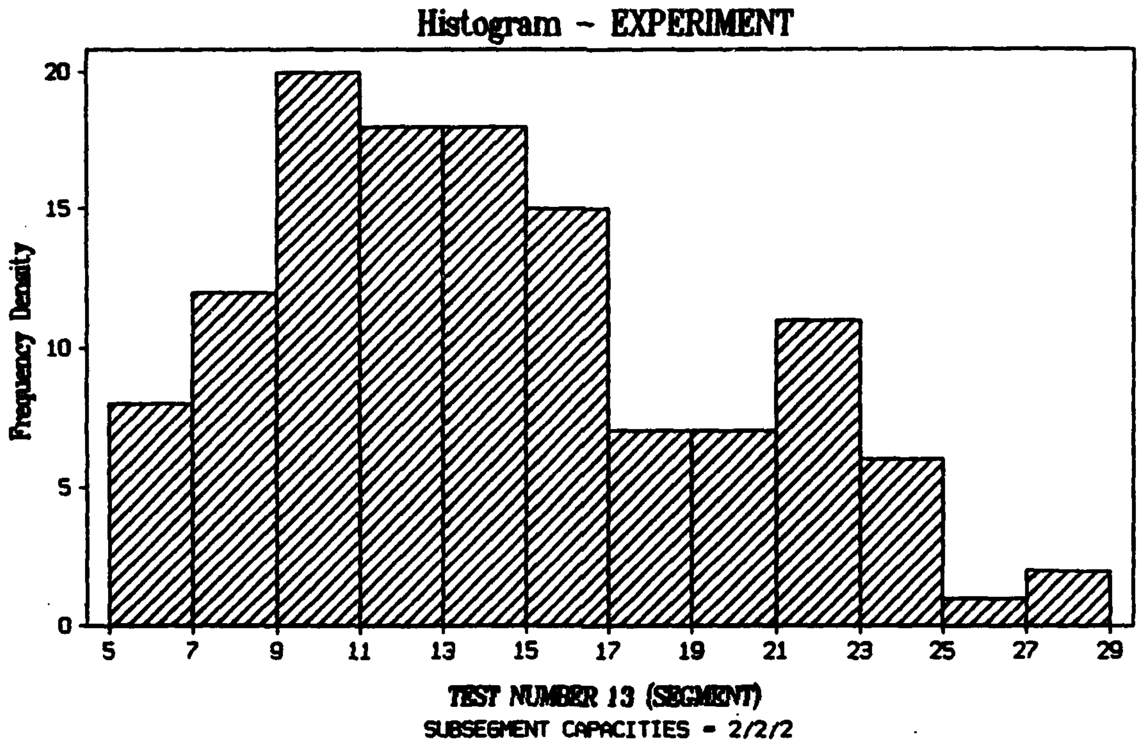


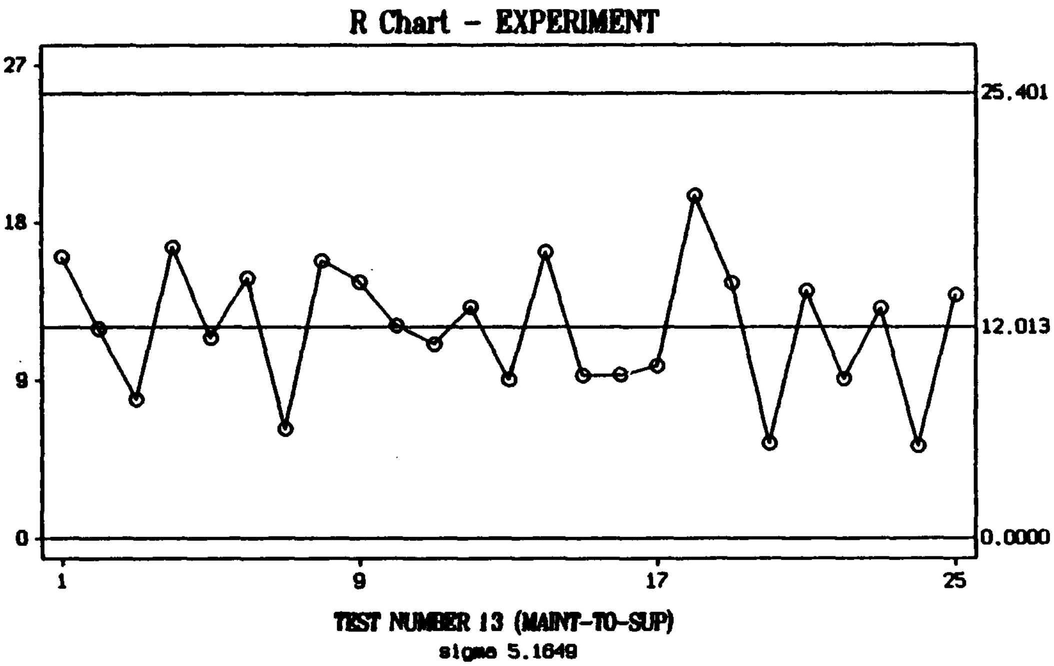
TEST NUMBER 13 (SEGMENT)
sigma 5.1484

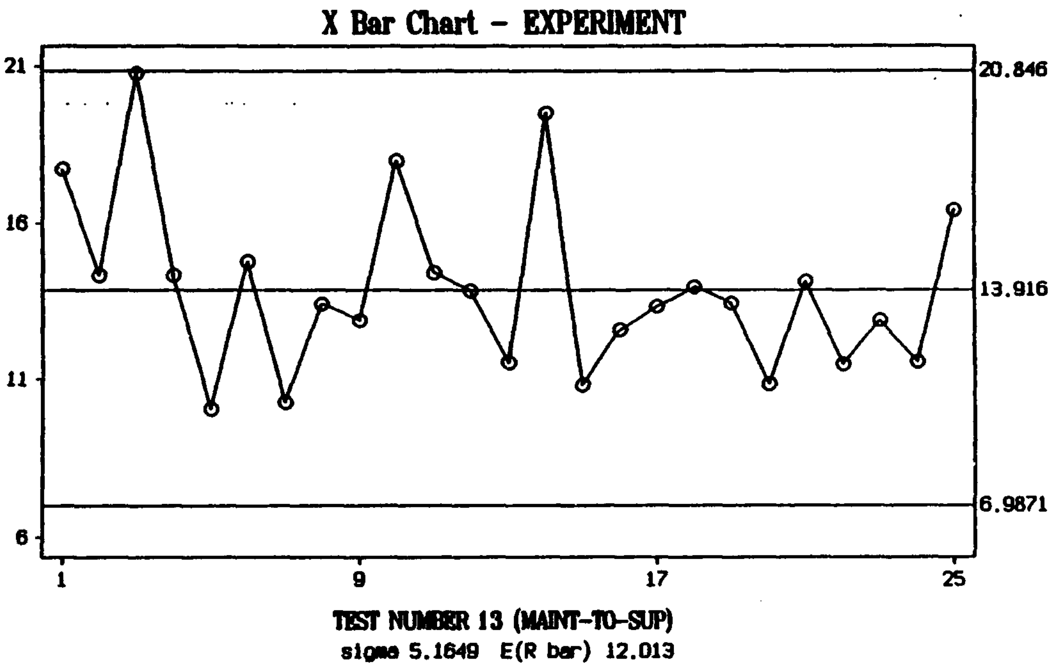
X Bar Chart - EXPERIMENT

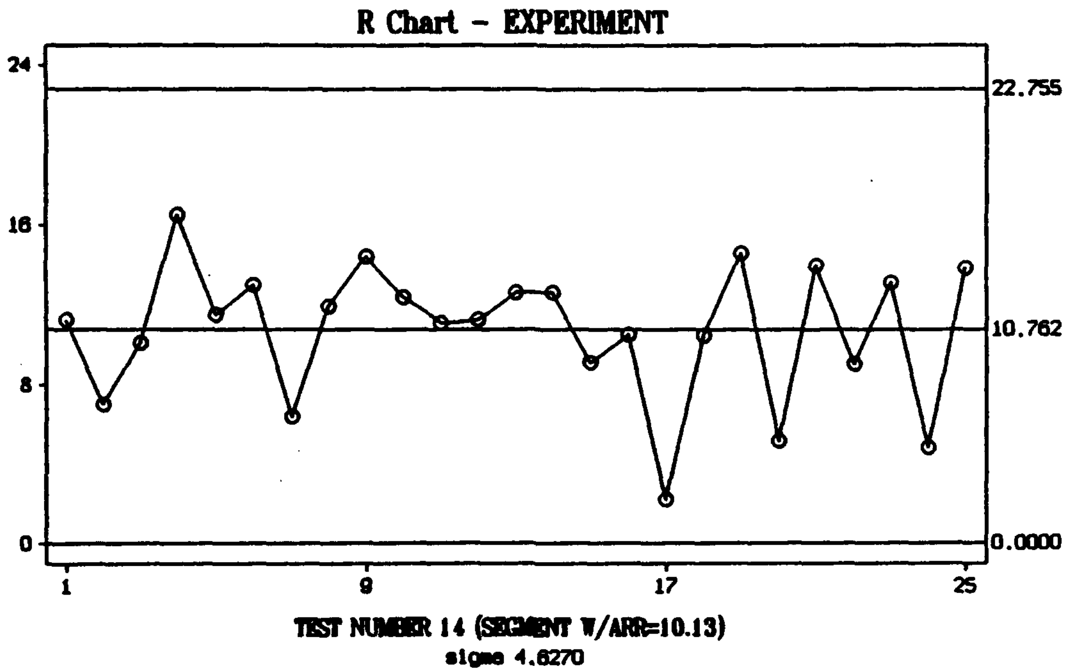


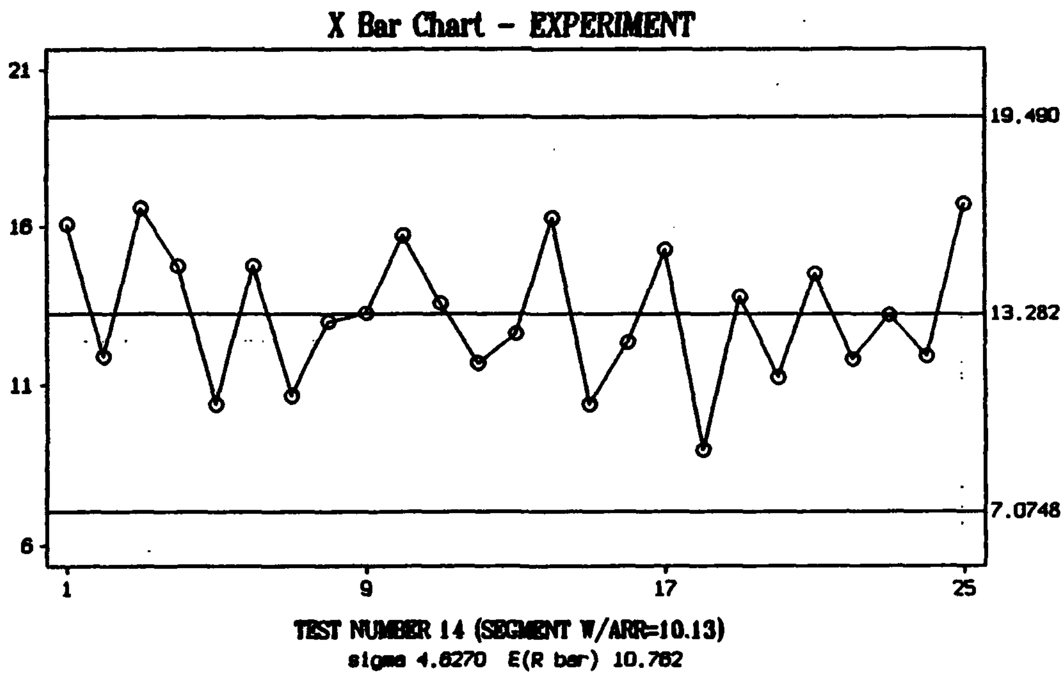
TEST NUMBER 13 (SEGMENT)
sigma 5.1484 E(R bar) 11.975

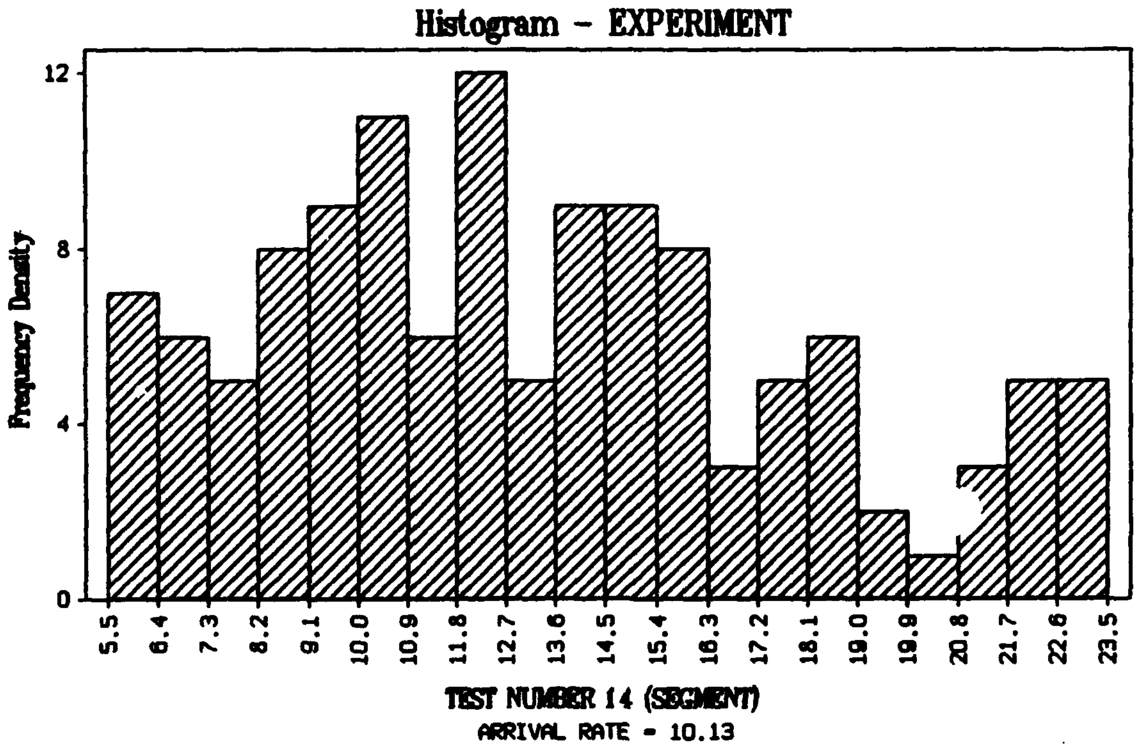

Histogram ~ EXPERIMENT
Frequency Density
0
5
10
15
20
5
7
9
11
13
15
17
19
21
23
25
27
29
TEST NUMBER 13 (SEGMENT)
SUBSEGMENT CAPACITIES = 2/2/2


R Chart - EXPERIMENT
27
18
9
0
25.401
12.013
0.0000
1
9
17
25
TEST NUMBER 13 (MAINT-TO-SUP)
sigma 5.1649


X Bar Chart - EXPERIMENT
21
16
11
6
20.846
13.916
6.9871
1
9
17
25
TEST NUMBER 13 (MAINT-TO-SUP)
sigma 5.1649 E(R bar) 12.013

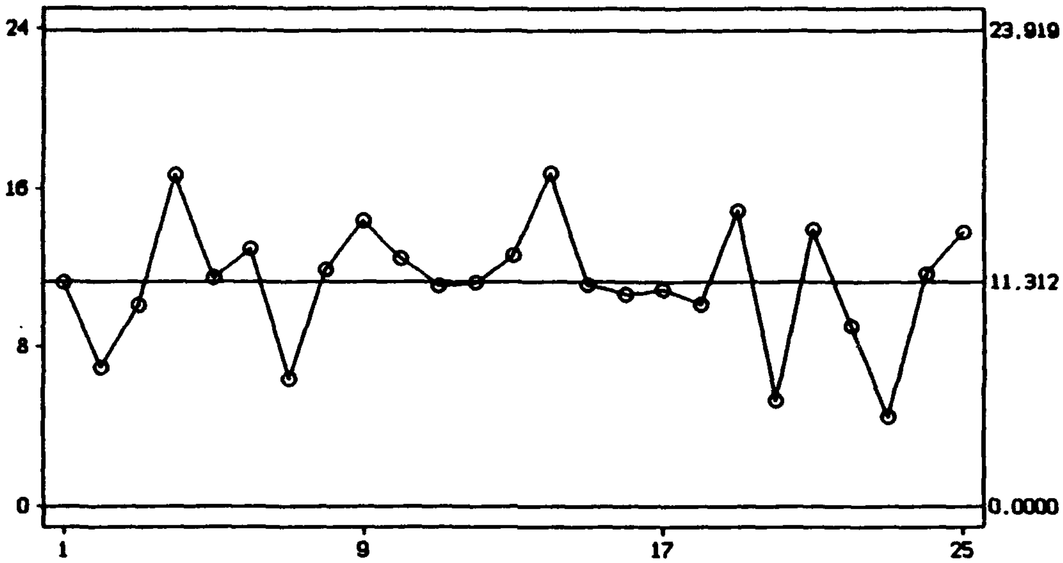

R Chart - EXPERIMENT
24
16
8
0
22.755
10.762
0.0000
1
9
17
25
TEST NUMBER 14 (SEGMENT W/ARR=10.13)
sigma 4.6270


X Bar Chart - EXPERIMENT
21
16
11
6
19.490
13.282
7.0748
1
9
17
25
TEST NUMBER 14 (SEGMENT W/ARR=10.13)
sigma 4.6270 E(R bar) 10.762



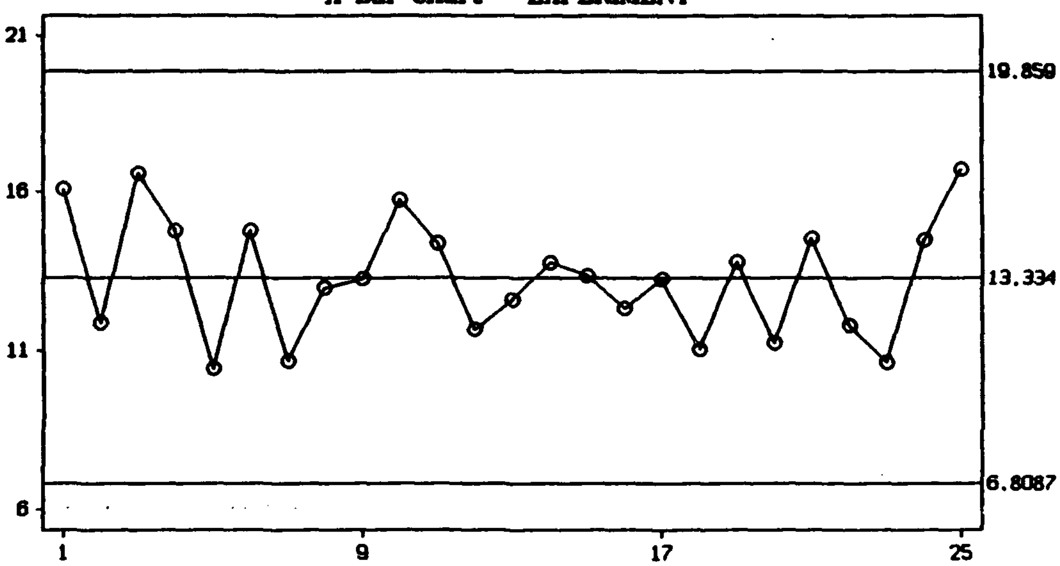
Histogram - EXPERIMENT
Frequency Density
0
4
8
12
5.5
6.4
7.3
8.2
9.1
10.0
10.9
11.8
12.7
13.6
14.5
15.4
16.3
17.2
18.1
19.0
19.9
20.8
21.7
22.6
23.5
TEST NUMBER 14 (SEGMENT)
ARRIVAL RATE = 10.13

R Chart - EXPERIMENT

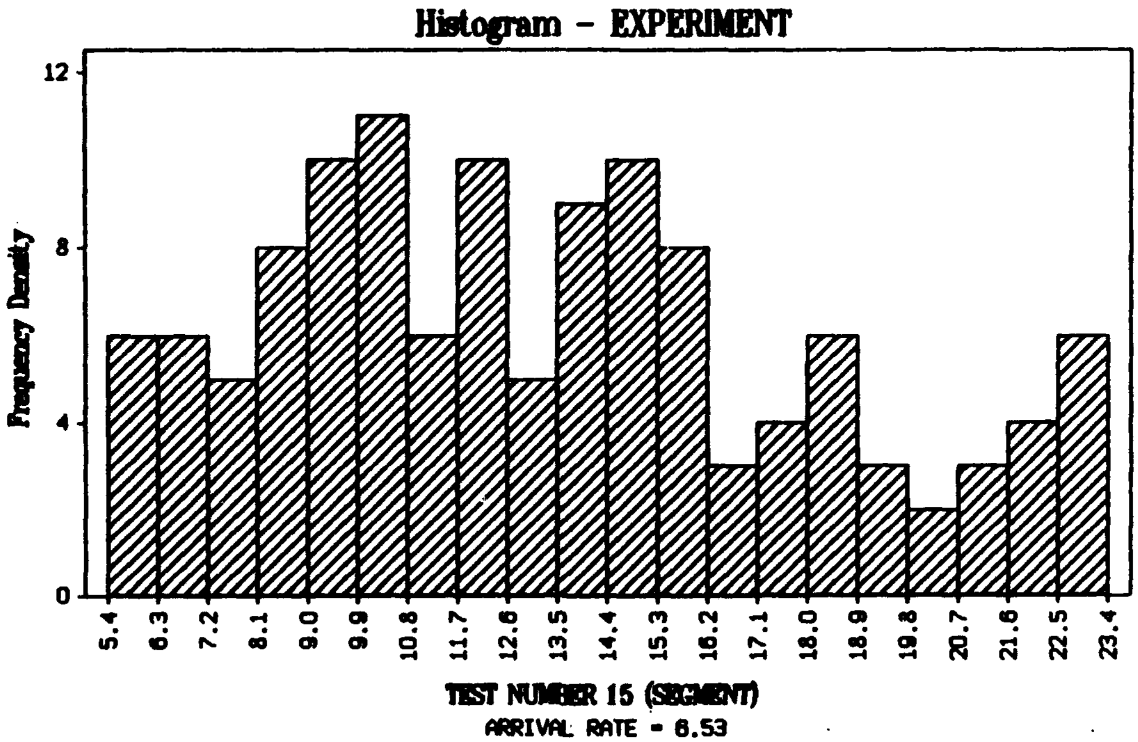


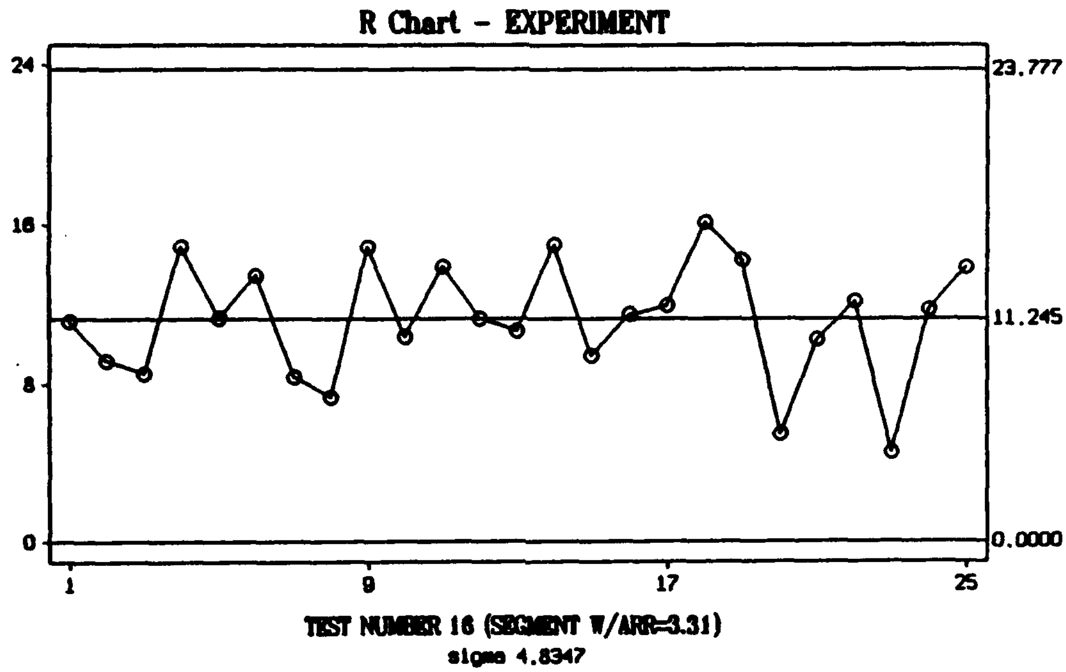
TEST NUMBER 15 (SEGMENT W/ARR=6.53)
sigma 4.8636

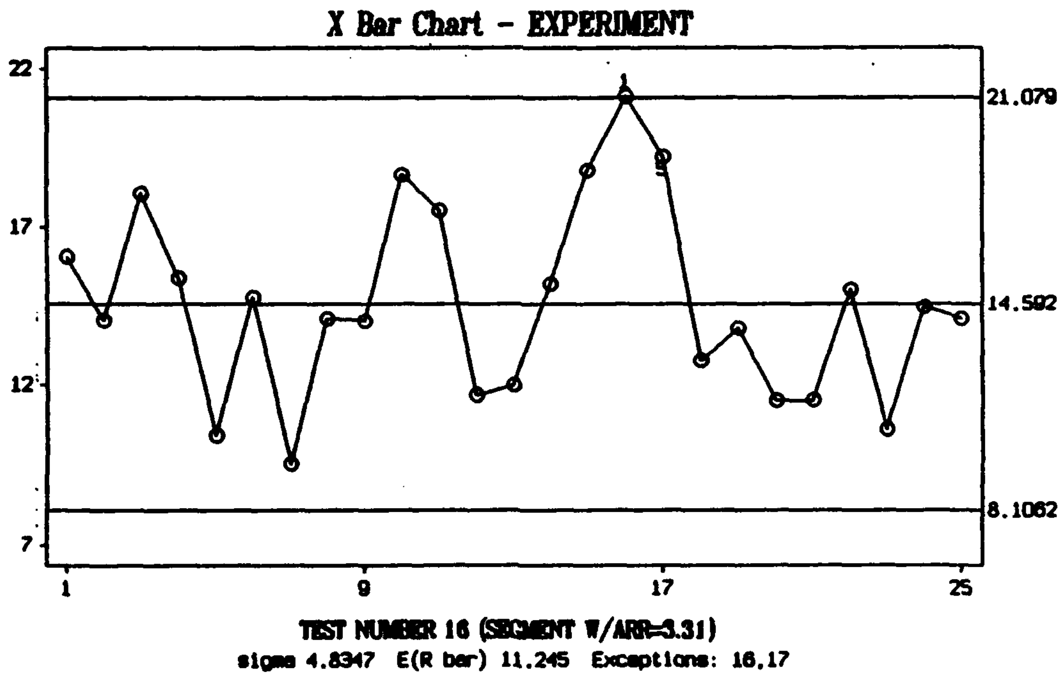
X Bar Chart - EXPERIMENT

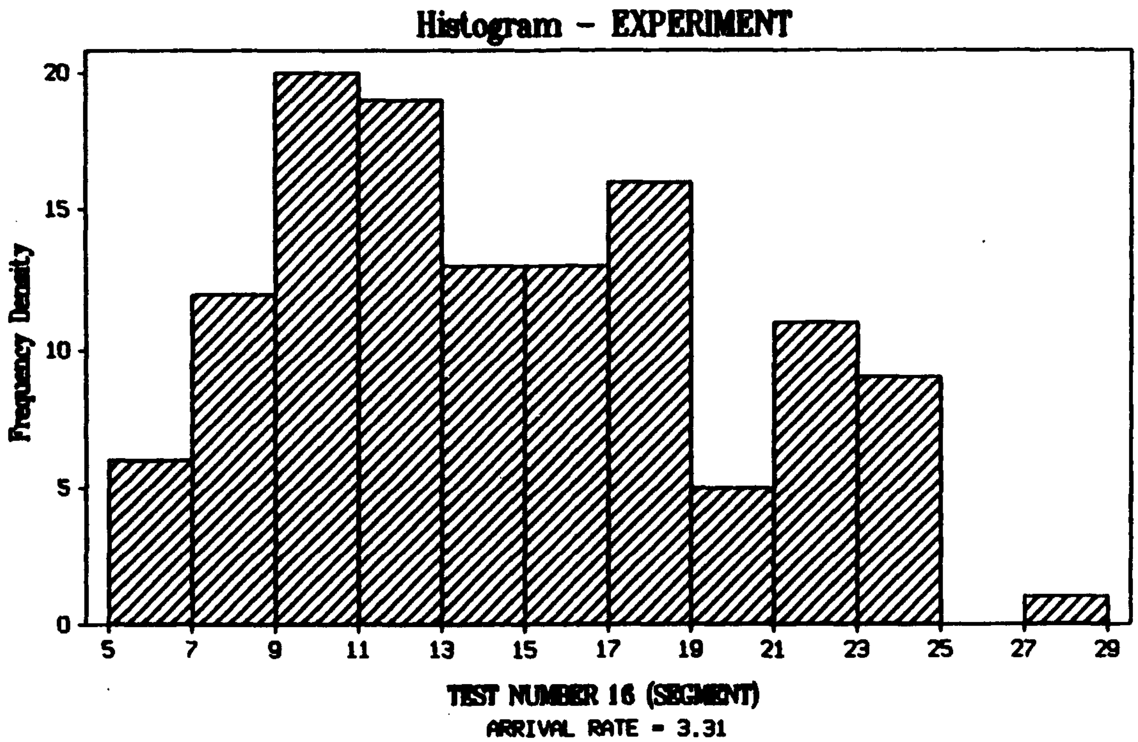


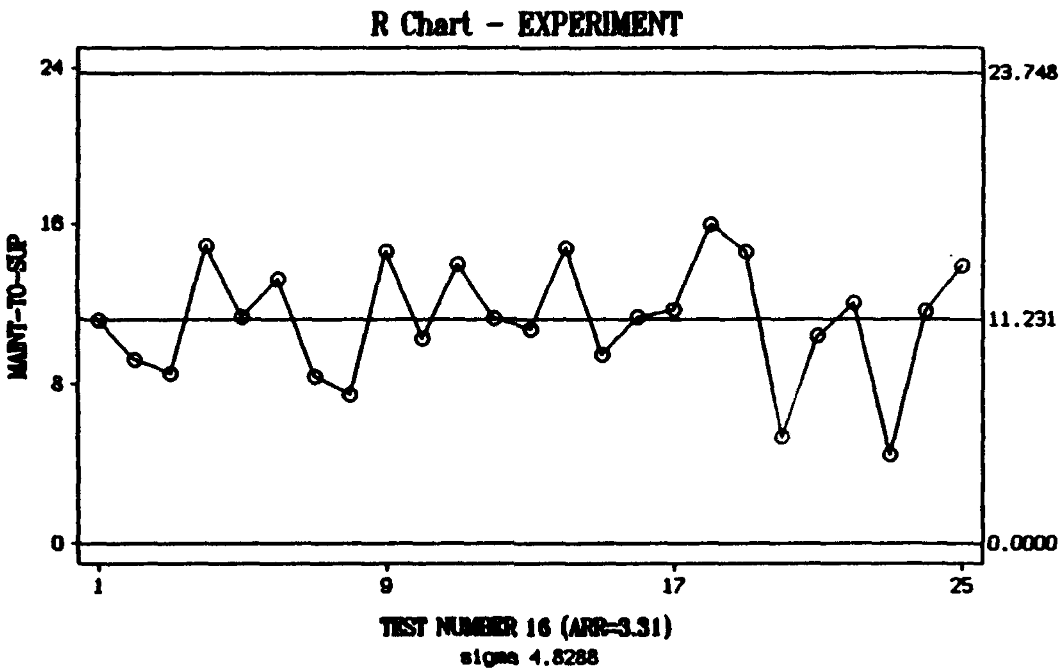
TEST NUMBER 15 (SEGMENT W/ARR=6.53)
sigma 4.8636 E(R bar) 11.312

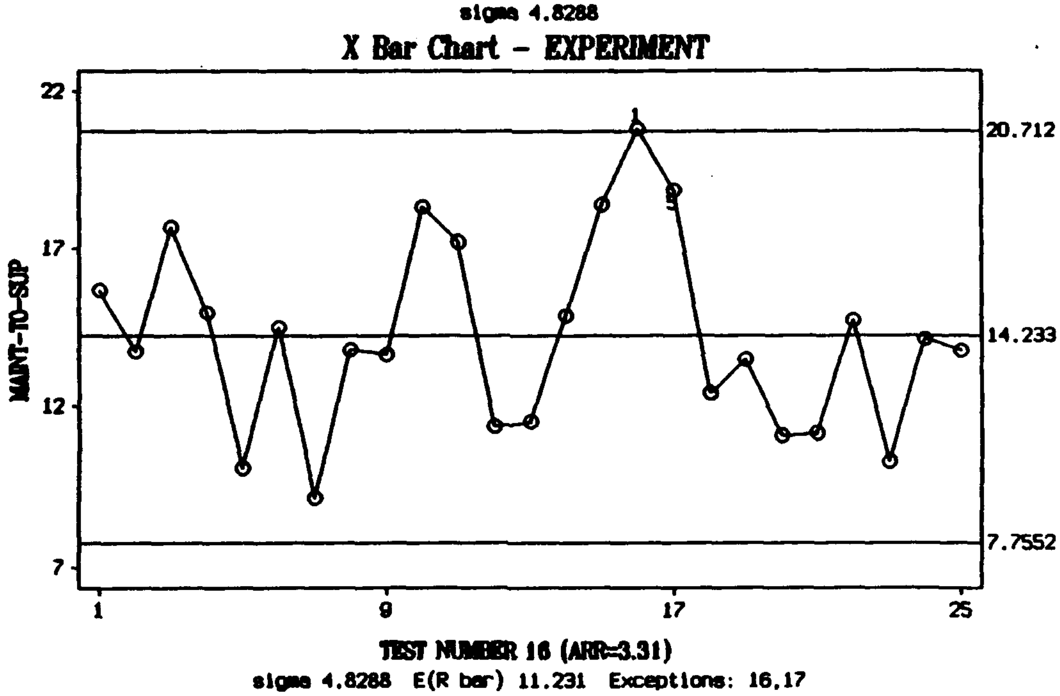

Histogram - EXPERIMENT
Frequency Density
0
4
8
12
5.4
6.3
7.2
8.1
9.0
9.9
10.8
11.7
12.6
13.5
14.4
15.3
16.2
17.1
18.0
18.9
19.8
20.7
21.6
22.5
23.4
TEST NUMBER 15 (SEGMENT)
ARRIVAL RATE = 6.53


R Chart - EXPERIMENT
24
16
8
0
23.777
11.245
0.0000
1
9
17
25
TEST NUMBER 16 (SEGMENT W/ARR=3.31)
sigma 4.8347

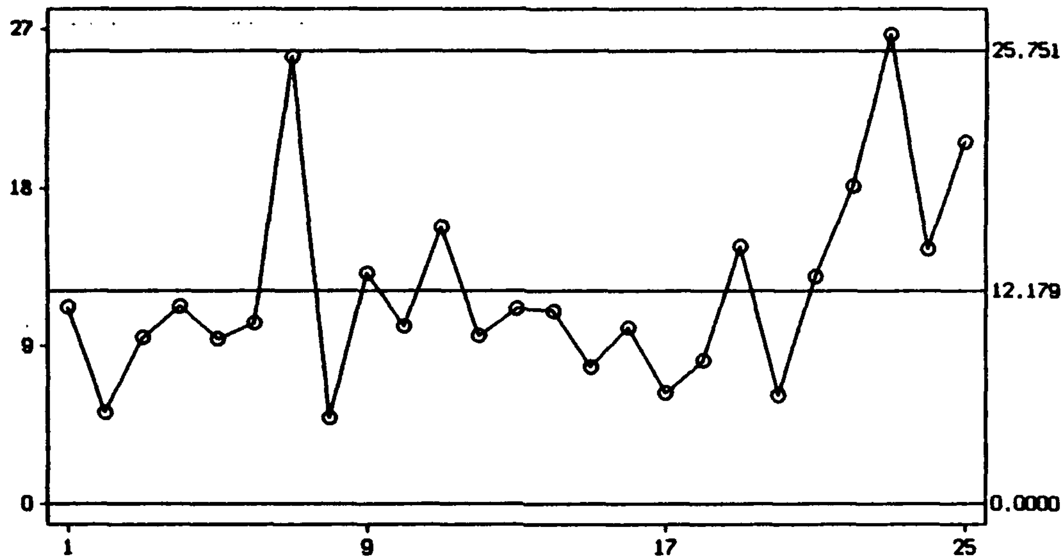

X Bar Chart - EXPERIMENT
22
17
12
7
21.079
14.592
8.1062
1
9
17
25
TEST NUMBER 16 (SEGMENT W/ARR=3.31)
sigma 4.8347 E(R bar) 11.245 Exceptions: 16,17


Histogram - EXPERIMENT
Frequency Density
0
5
10
15
20
5 7 9 11 13 15 17 19 21 23 25 27 29
TEST NUMBER 16 (SEGMENT)
ARRIVAL RATE = 3.31


R Chart - EXPERIMENT
24
16
8
0
23.748
11.231
0.0000
MAINT-TO-SUP
1
9
17
25
TEST NUMBER 16 (ARR=3.31)
sigma 4.8288


X Bar Chart - EXPERIMENT
22
17
12
7
20.712
14.233
7.7552
MAINT-TO-SUP
1
9
17
25
TEST NUMBER 16 (ARR=3.31)
sigma 4.8288 E(R bar) 11.231 Exceptions: 16,17

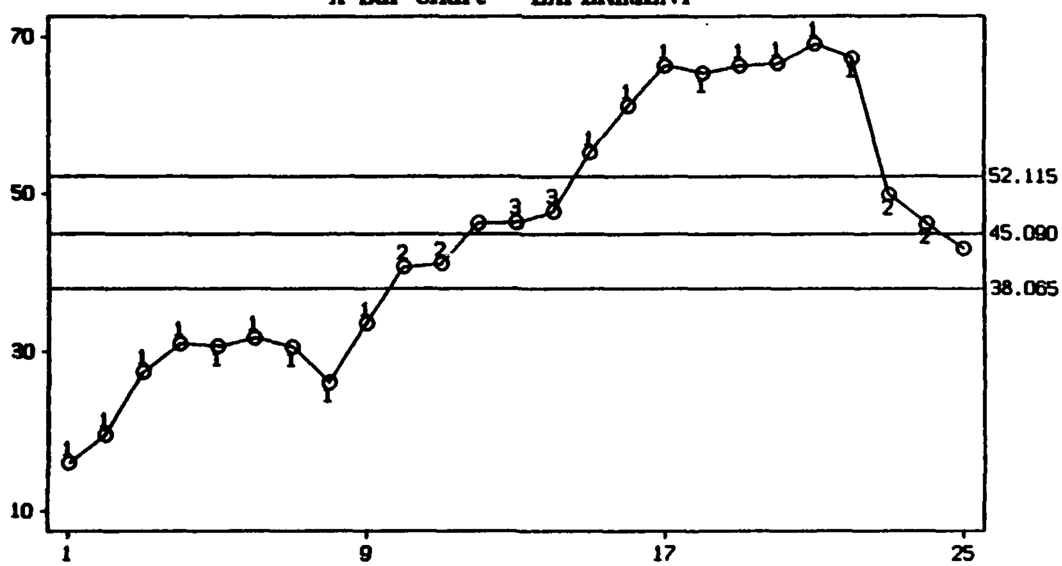
R Chart - EXPERIMENT



TEST NUMBER 17 (SEGMENT W/ARR=2.00)

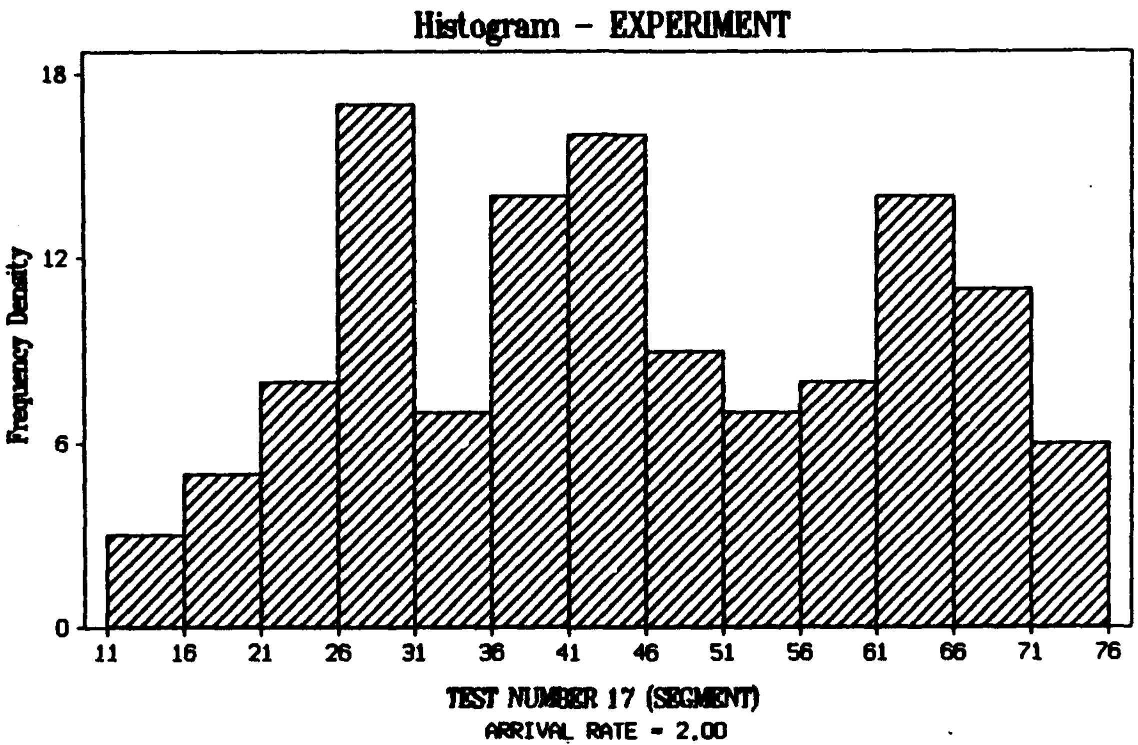
sigma 5.2362 Exceptions: 23

X Bar Chart - EXPERIMENT

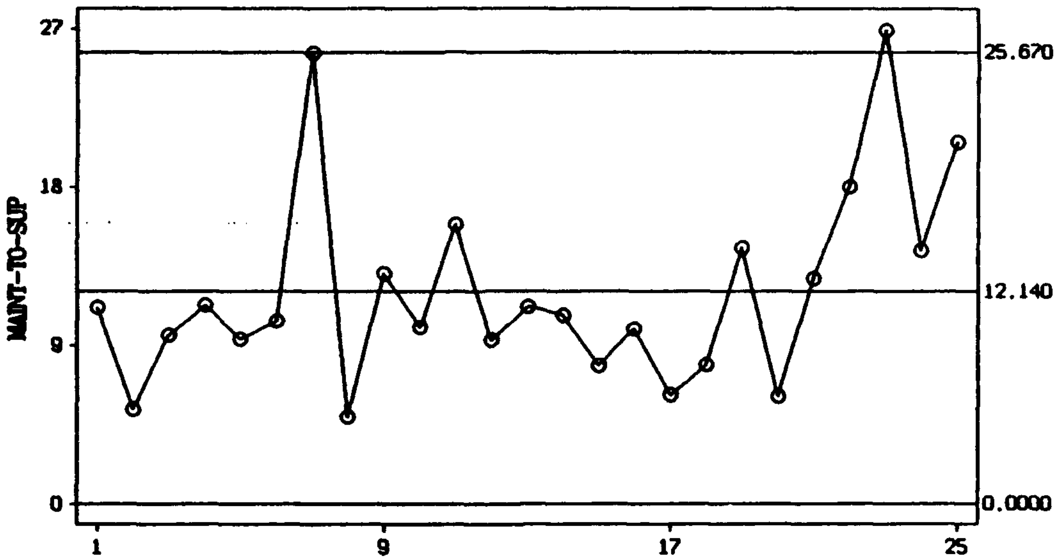


TEST NUMBER 17 (SEGMENT W/ARR=2.00)

sigma 5.2362 E(R bar) 12.179 Exceptions: 1,2,3,4,5,6,7,8,9,10,11,13,14 ...

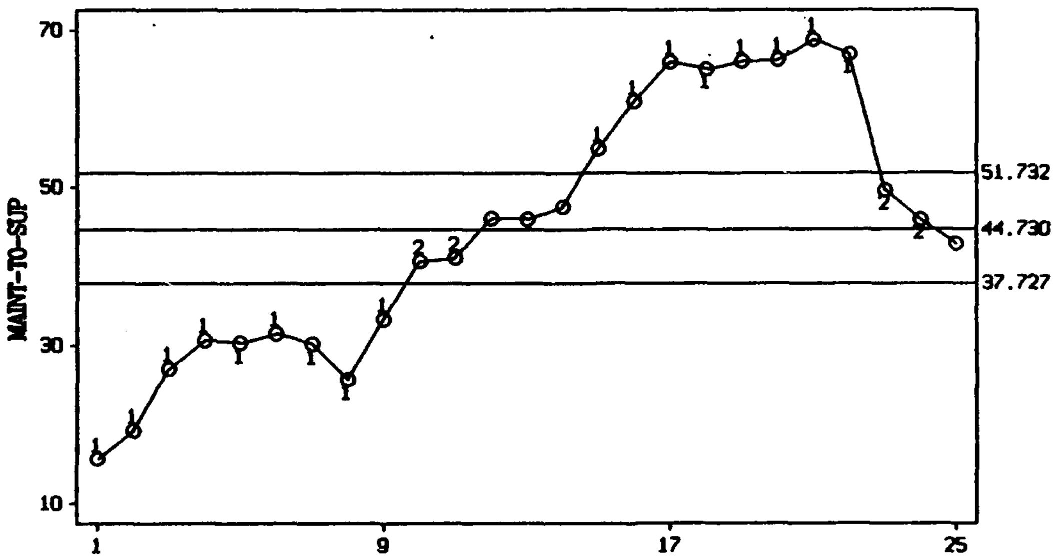

Histogram - EXPERIMENT
Frequency Density
18
12
6
0
11
16
21
26
31
36
41
46
51
56
61
66
71
76
TEST NUMBER 17 (SEGMENT)
ARRIVAL RATE = 2.00

R Chart - EXPERIMENT



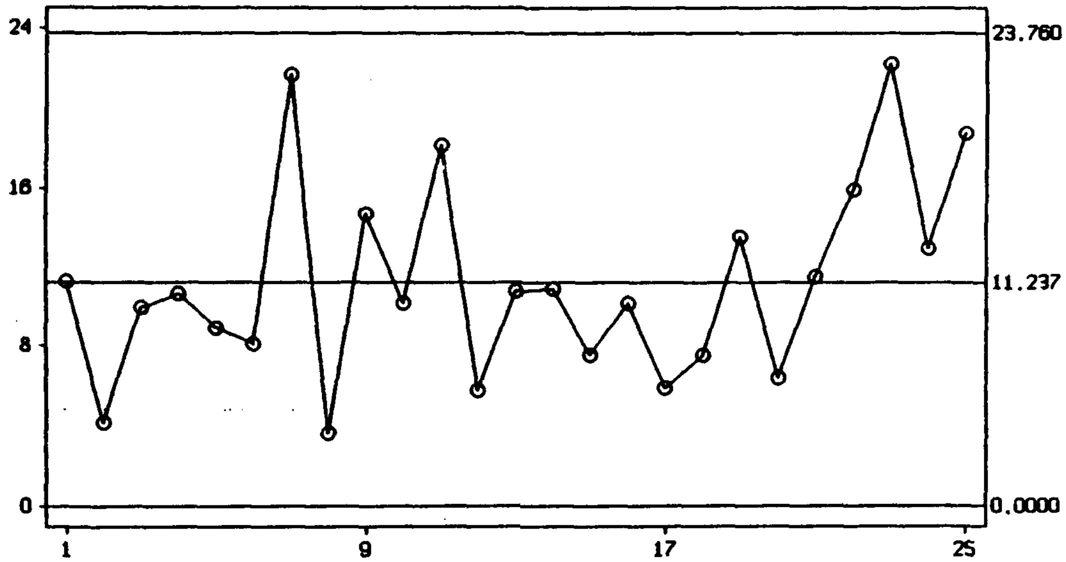
TEST NUMBER 17 (ARR=2.00)
sigma 5.2196 Exceptions: 23

X Bar Chart - EXPERIMENT



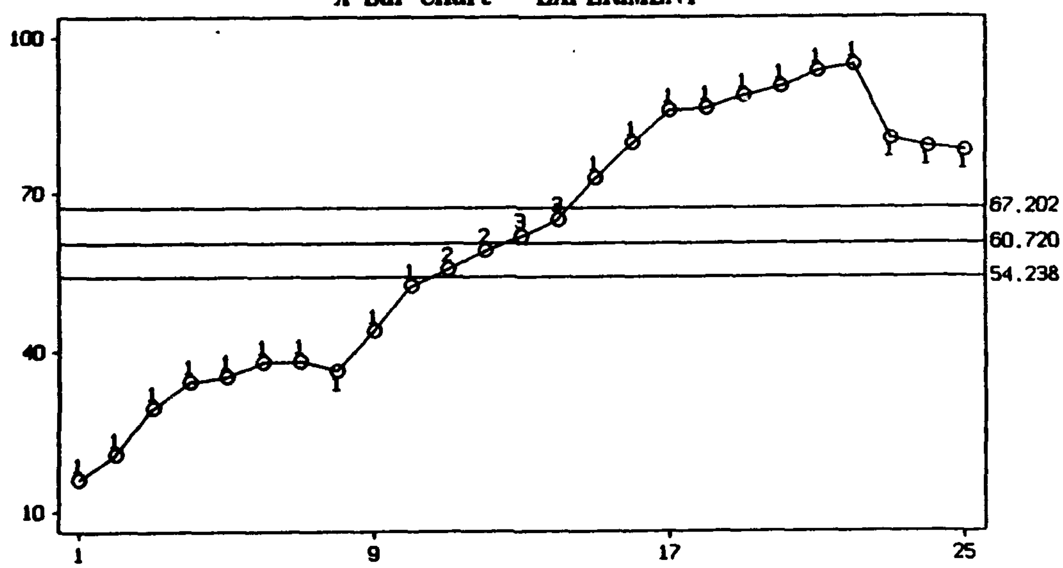
TEST NUMBER 17 (ARR=2.00)
sigma 5.2196 E(R bar) 12.140 Exceptions: 1,2,3,4,5,6,7,8,9,10,11,15,16 ...

R Chart - EXPERIMENT

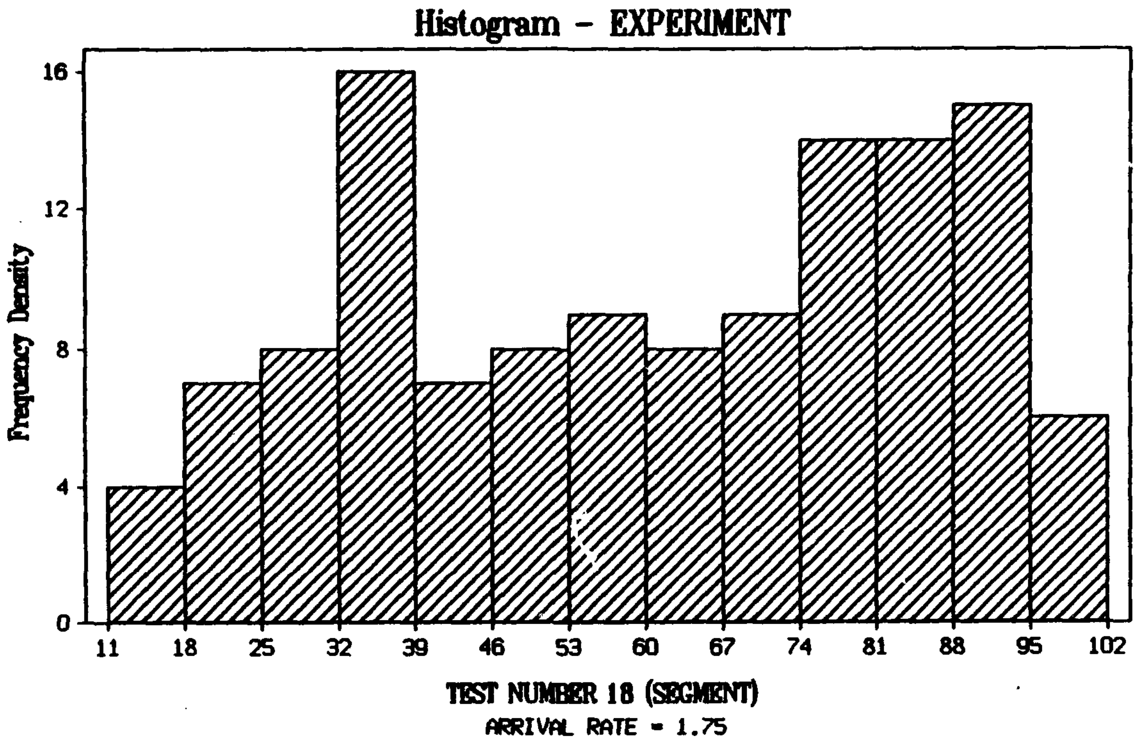


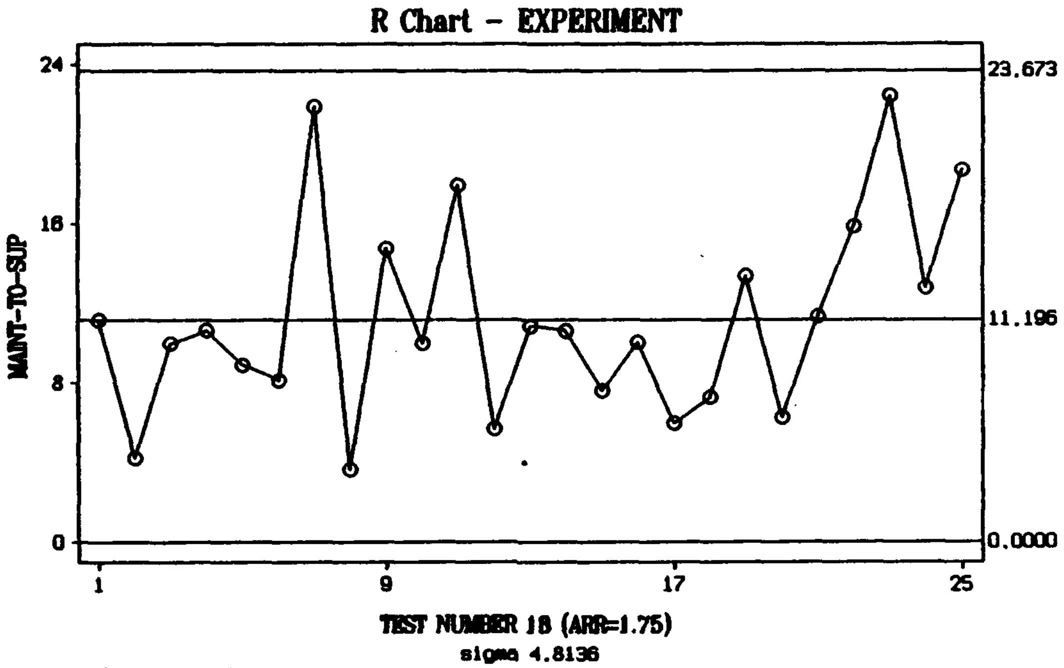
TEST NUMBER 18 (SEGMENT W/ARR=1.75)
sigma 4.8313

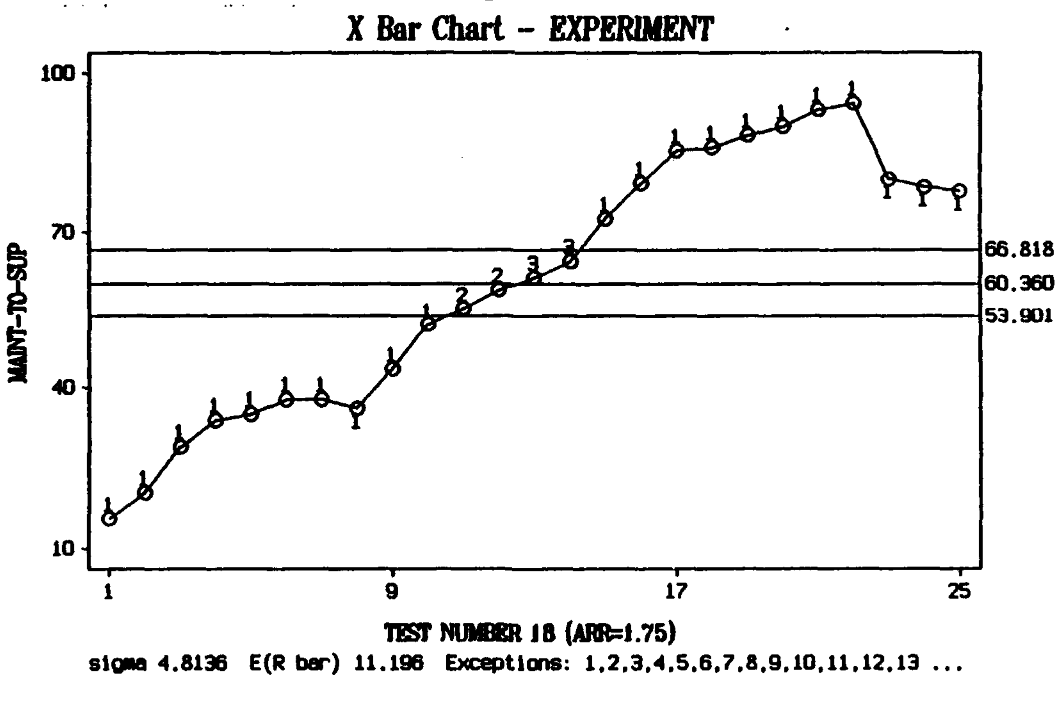
X Bar Chart - EXPERIMENT

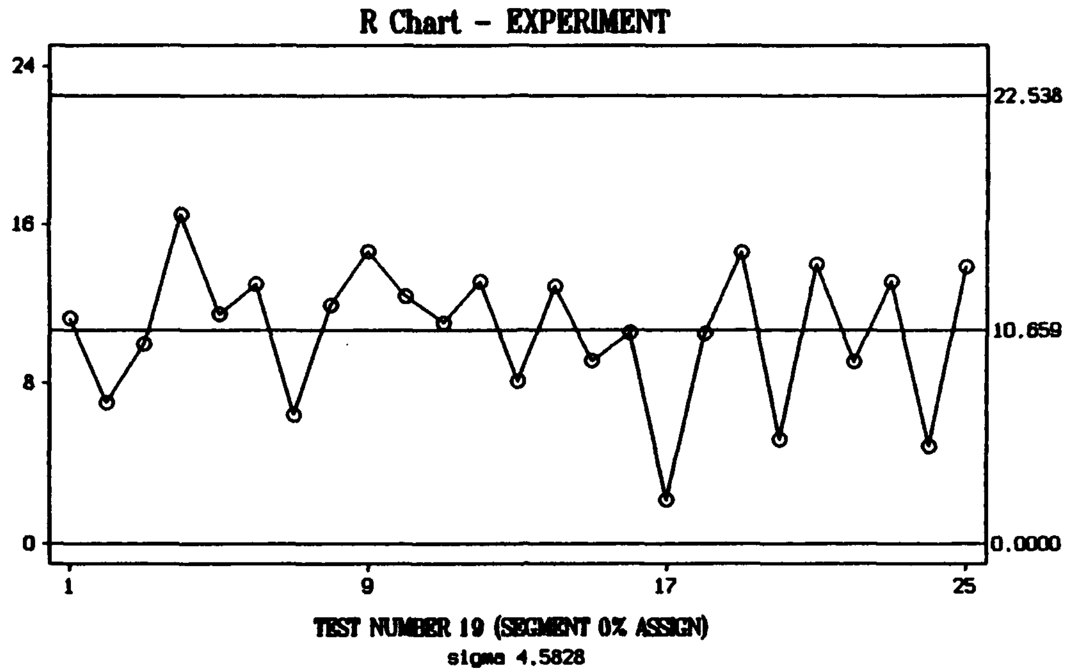


TEST NUMBER 18 (SEGMENT W/ARR=1.75)
sigma 4.8313 E(R bar) 11.237 Exceptions: 1,2,3,4,5,6,7,8,9,10,11,12,13 ...

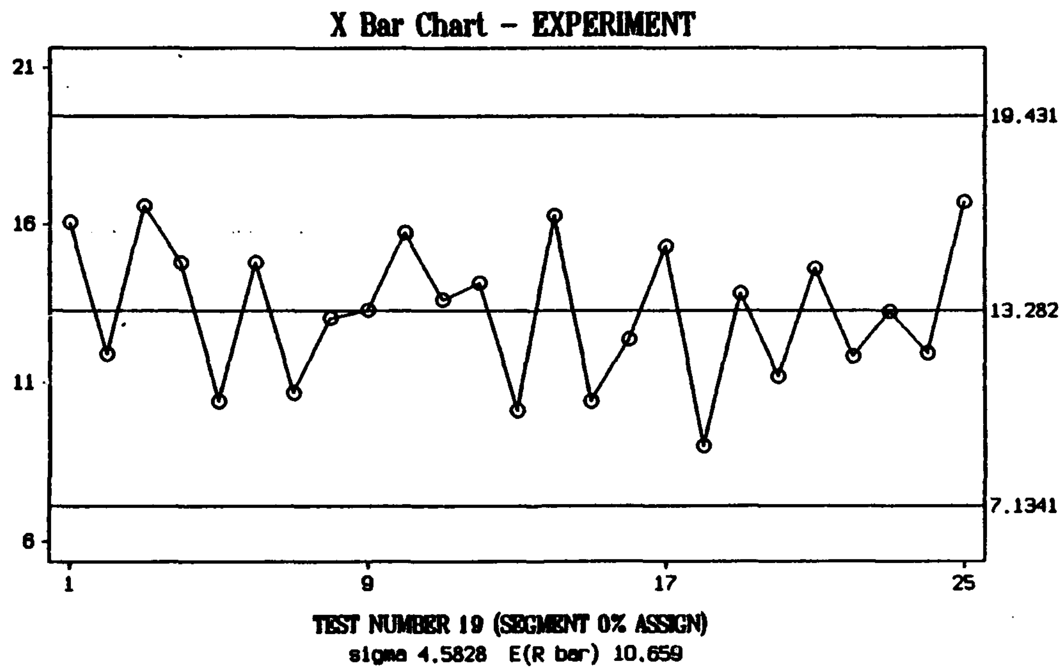

Histogram - EXPERIMENT
Frequency Density
0
4
8
12
16
11
18
25
32
39
46
53
60
67
74
81
88
95
102
TEST NUMBER 18 (SEGMENT)
ARRIVAL RATE = 1.75


R Chart - EXPERIMENT
MAINT-TO-SUP
24
16
8
0
23.673
11.196
0.0000
1
9
17
25
TEST NUMBER 18 (ARR=1.75)
sigma 4.8136

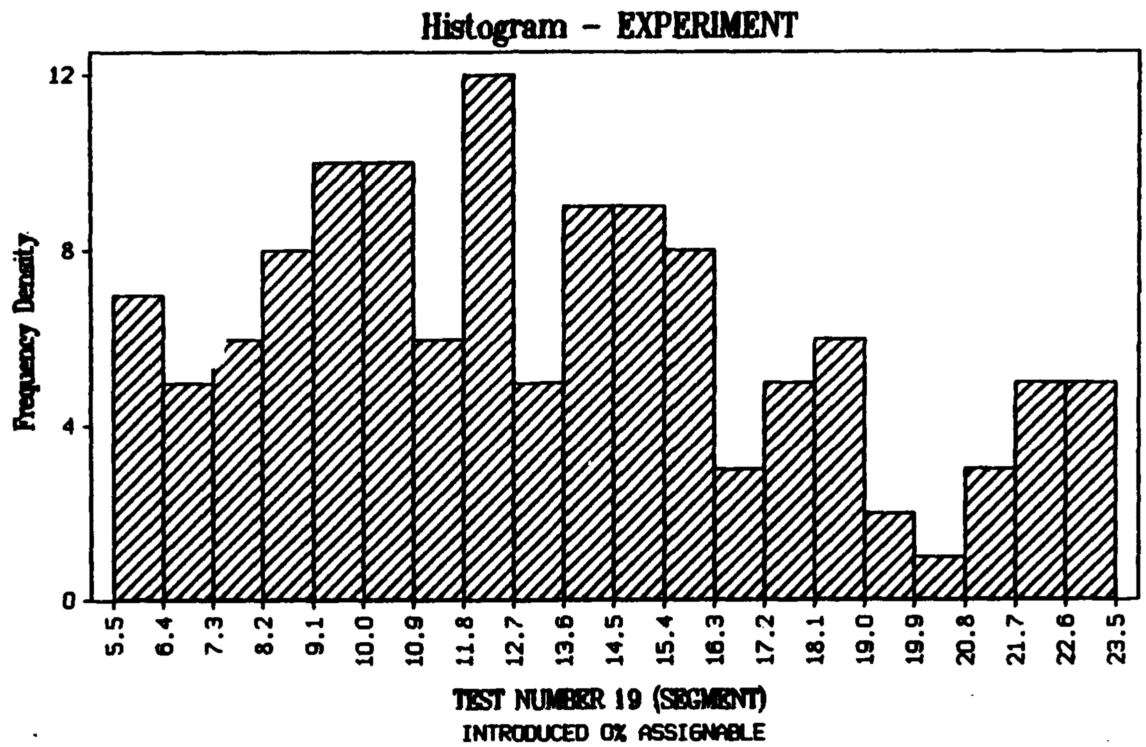

X Bar Chart - EXPERIMENT
MAINT-TO-SUP
100
70
40
10
66.818
60.360
53.901
1
9
17
25
TEST NUMBER 18 (ARR=1.75)
sigma 4.8136 E(R bar) 11.196 Exceptions: 1,2,3,4,5,6,7,8,9,10,11,12,13 ...

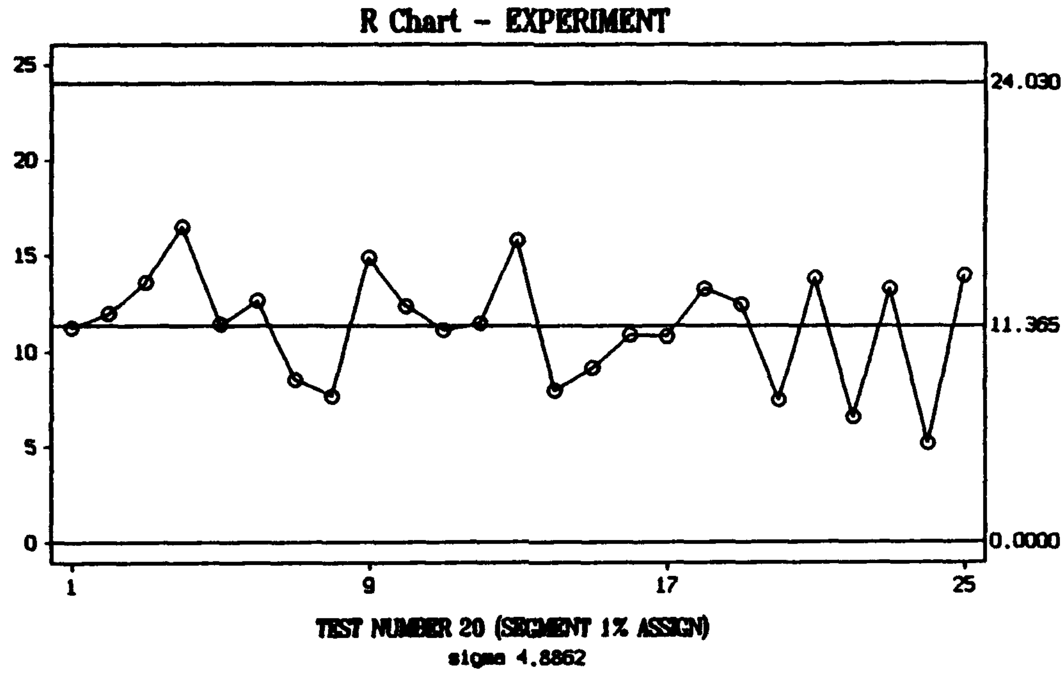


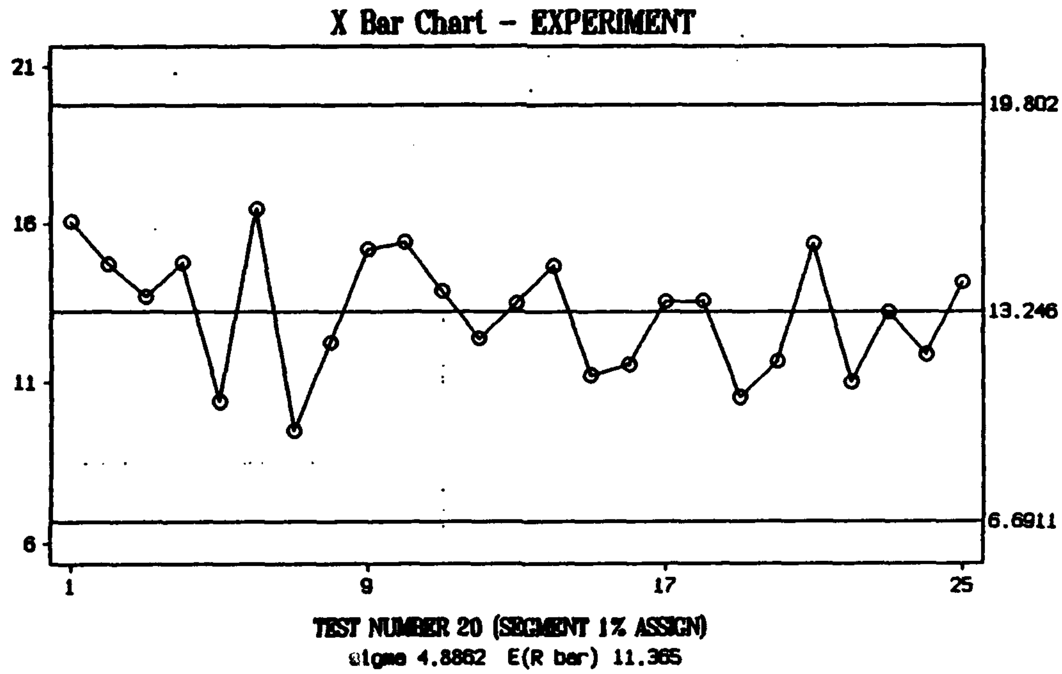
R Chart - EXPERIMENT
24
16
8
0
22.538
10.659
0.0000
1
9
17
25
TEST NUMBER 19 (SEGMENT 0% ASSIGN)
sigma 4.5828

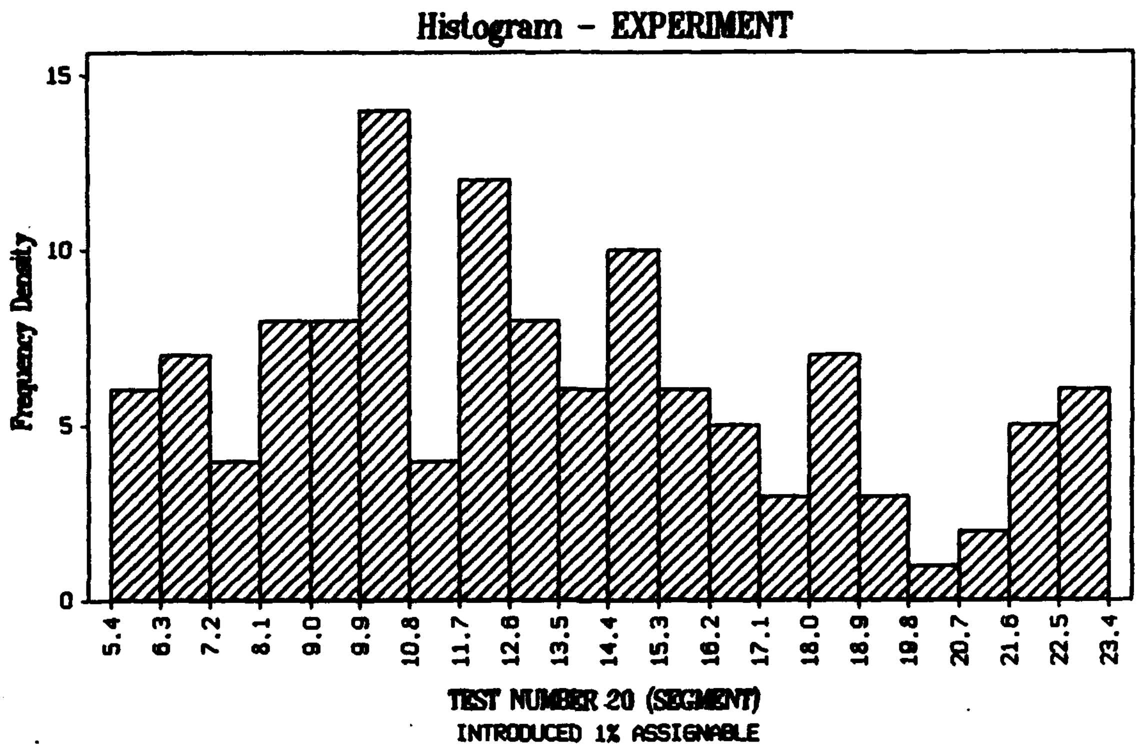


X Bar Chart - EXPERIMENT
21
16
11
6
19.431
13.282
7.1341
1
9
17
25
TEST NUMBER 19 (SEGMENT 0% ASSIGN)
sigma 4.5828 E(R bar) 10.659


Histogram - EXPERIMENT
Frequency Density
0
4
8
12
5.5
6.4
7.3
8.2
9.1
10.0
10.9
11.8
12.7
13.6
14.5
15.4
16.3
17.2
18.1
19.0
19.9
20.8
21.7
22.6
23.5
TEST NUMBER 19 (SEGMENT)
INTRODUCED 0% ASSIGNABLE

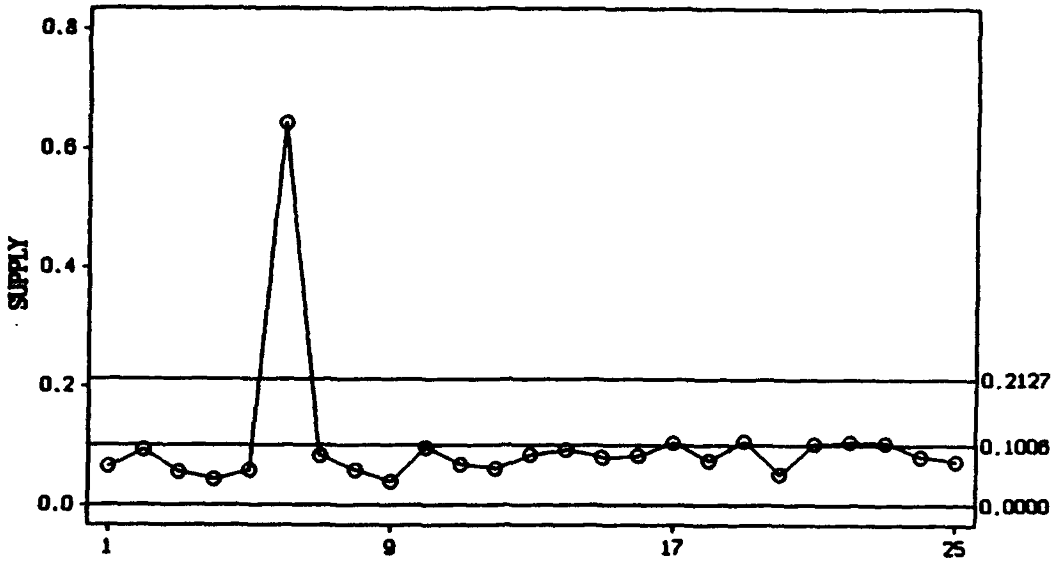

R Chart - EXPERIMENT
25
20
15
10
5
0
24.030
11.365
0.0000
1
9
17
25
TEST NUMBER 20 (SEGMENT 1% ASSIGN)
sigma 4.8862


X Bar Chart - EXPERIMENT
21
16
11
6
19.802
13.246
6.6911
1
9
17
25
TEST NUMBER 20 (SEGMENT 1% ASSIGN)
sigma 4.8862 E(R bar) 11.365



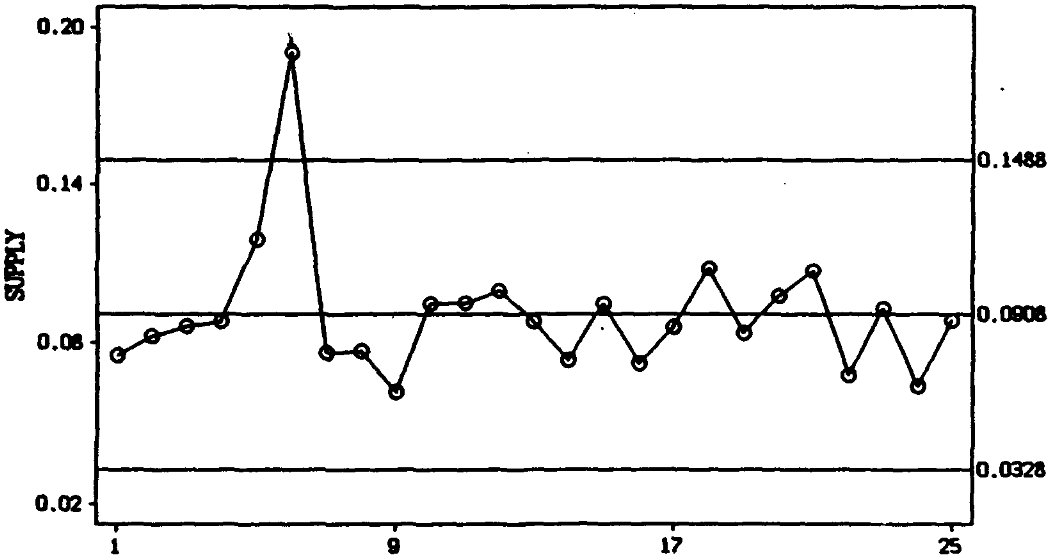
Histogram - EXPERIMENT
Frequency Density
15
10
5
0
5.4
6.3
7.2
8.1
9.0
9.9
10.8
11.7
12.6
13.5
14.4
15.3
16.2
17.1
18.0
18.9
19.8
20.7
21.6
22.5
23.4
TEST NUMBER 20 (SEGMENT)
INTRODUCED 1% ASSIGNABLE

R Chart - EXPERIMENT

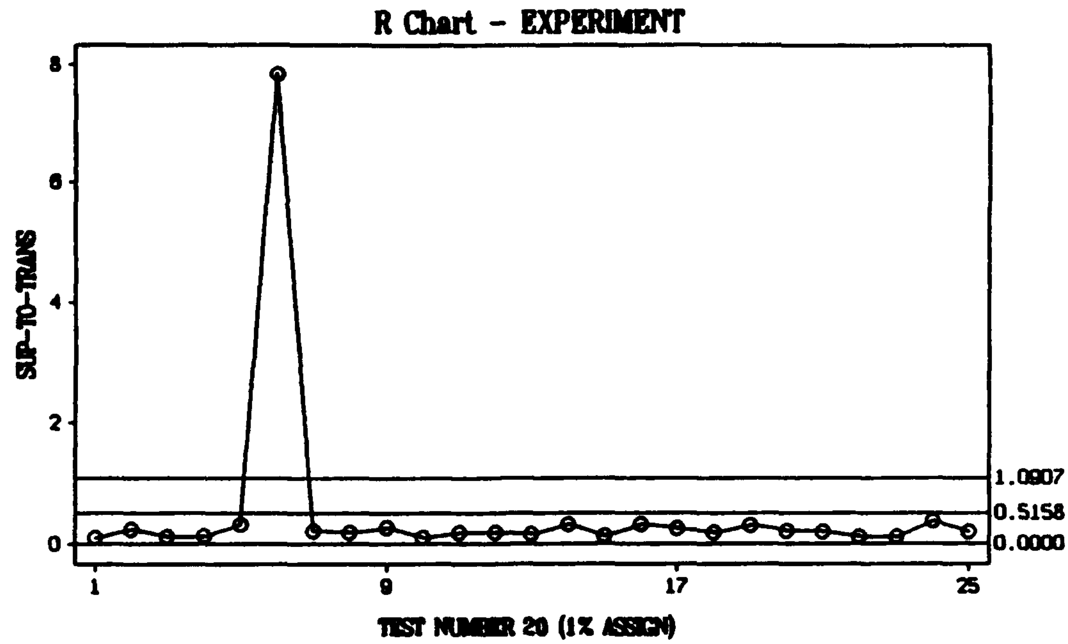


TEST NUMBER 20 (1% ASSIGN)
sigma 0.0432 Exceptions: 6

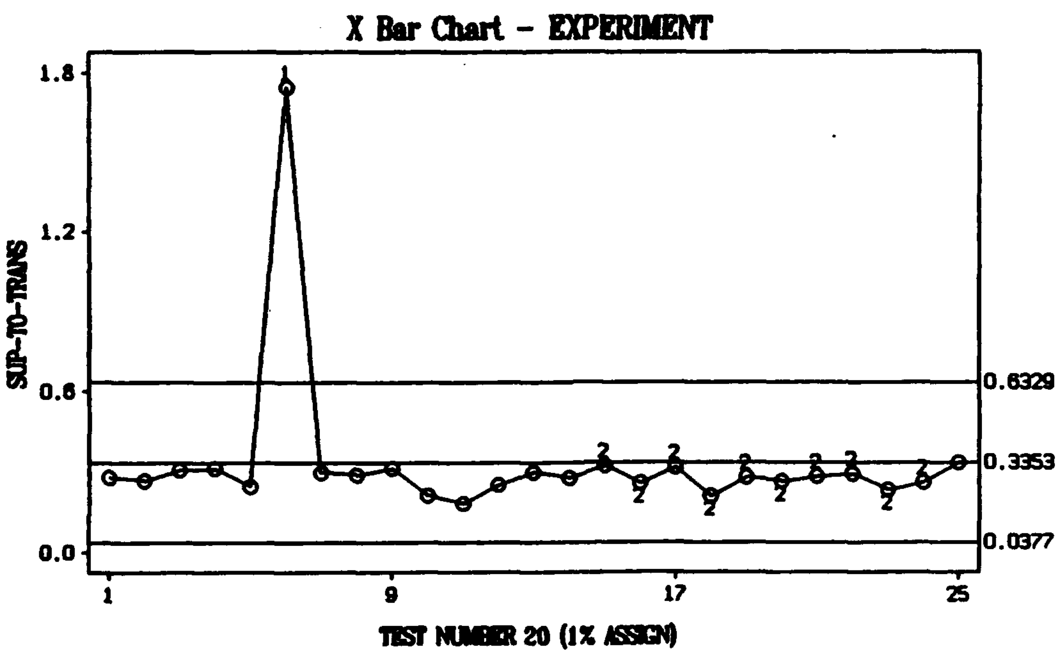
X Bar Chart - EXPERIMENT



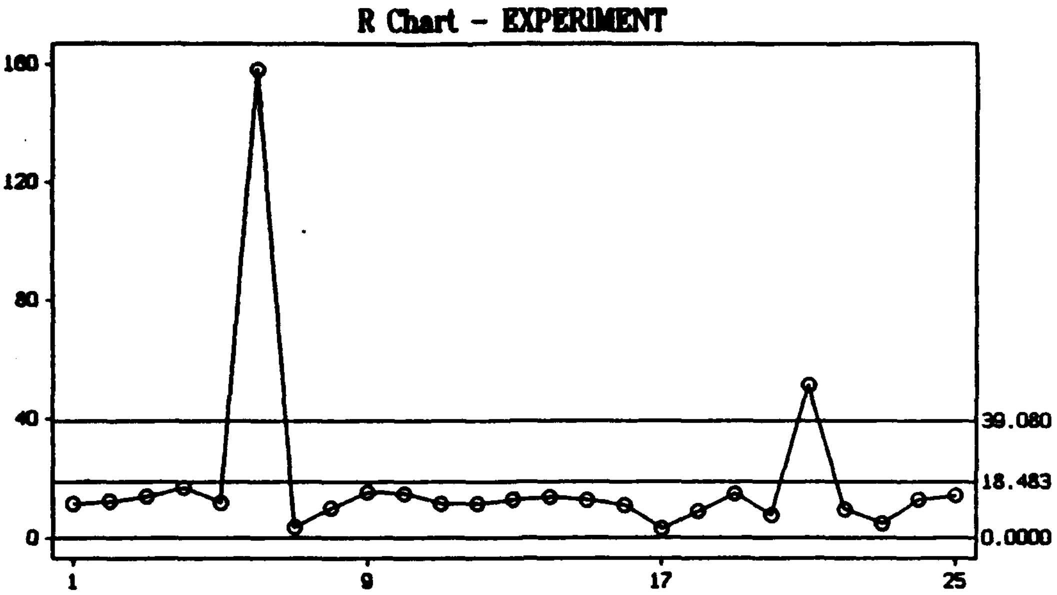
TEST NUMBER 20 (1% ASSIGN)
sigma 0.0432 E(R bar) 0.1006 Exceptions: 6



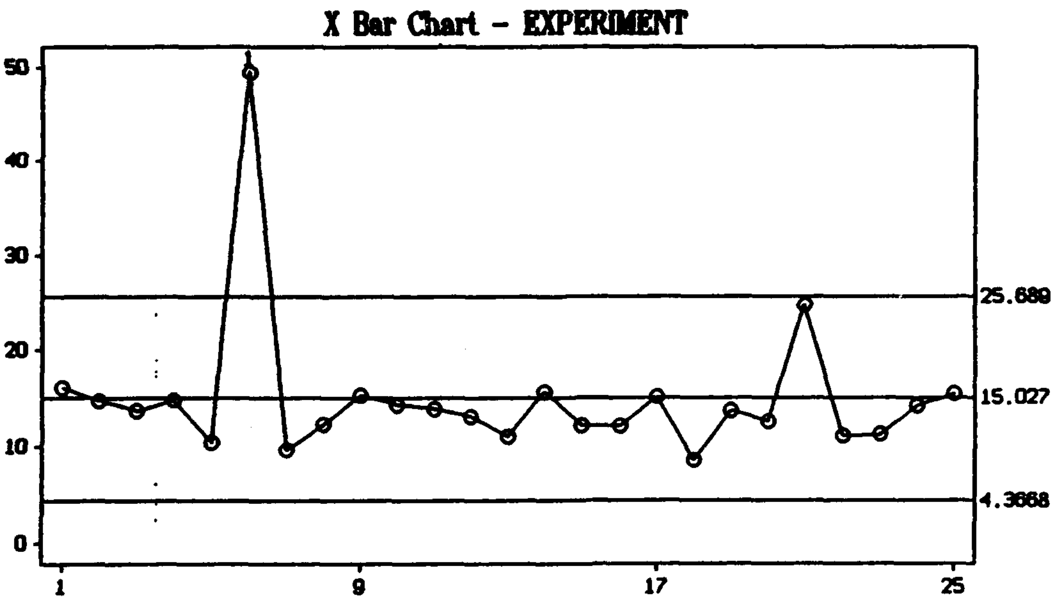
sigma 0.2217 Exceptions: 6



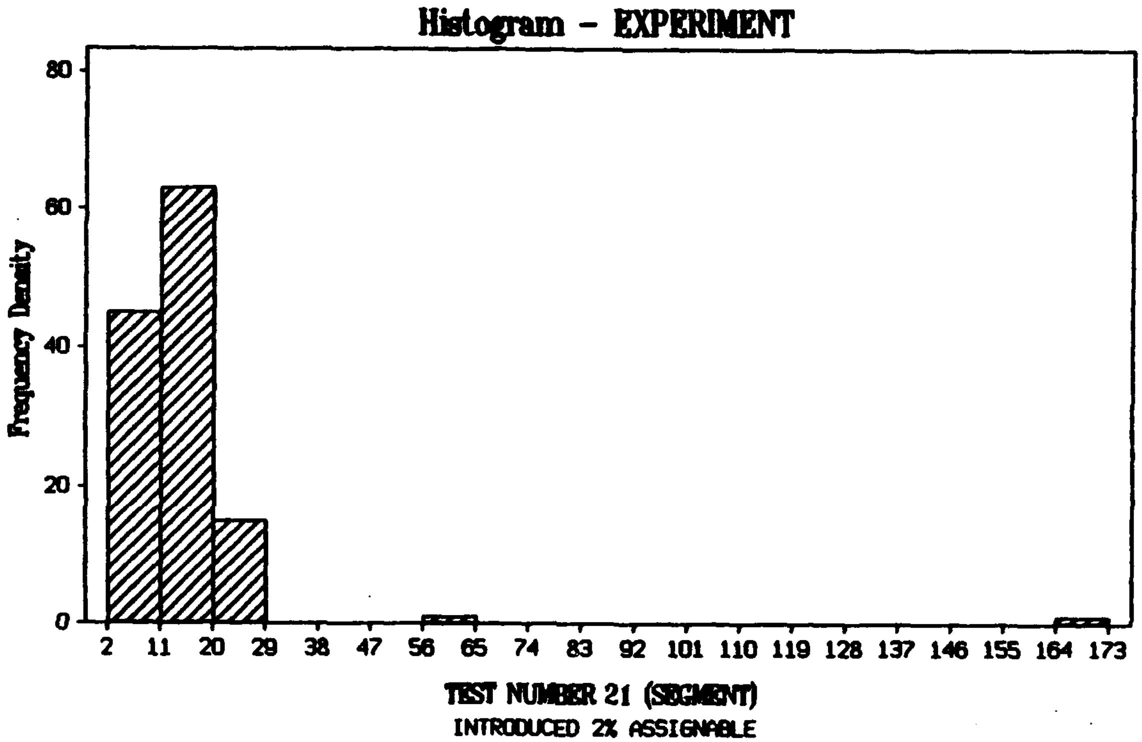
sigma 0.2217 E(R bar) 0.5158 Exceptions: 6,15,16,17,18,19,20,21,22,23,24



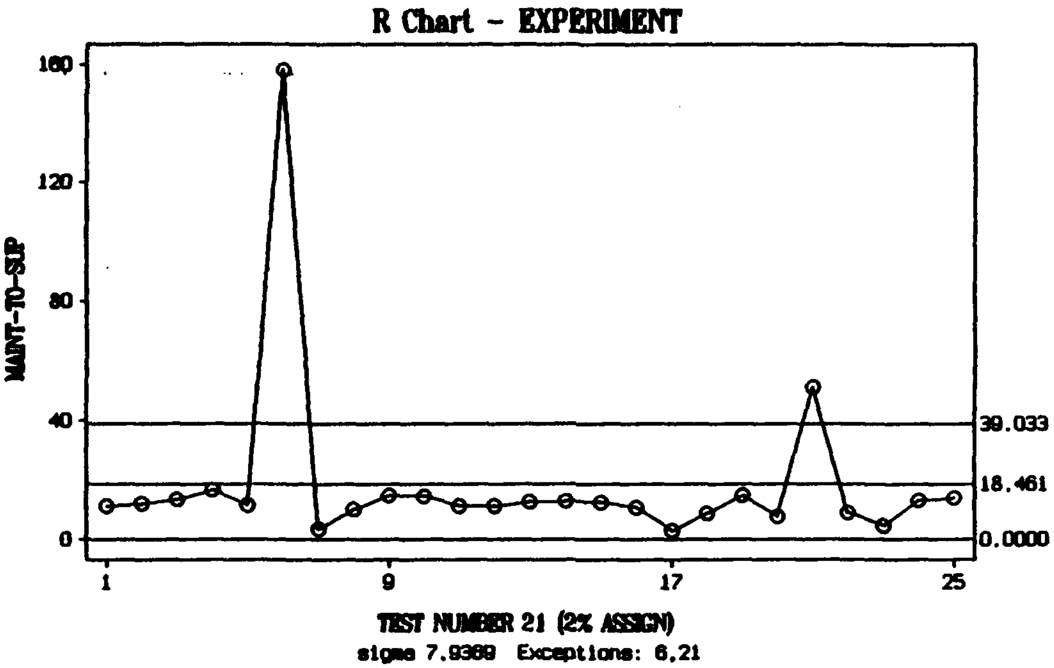
TEST NUMBER 21 (SEGMENT 2% ASSIGN)
sigma 7.9463 Exceptions: 6,21

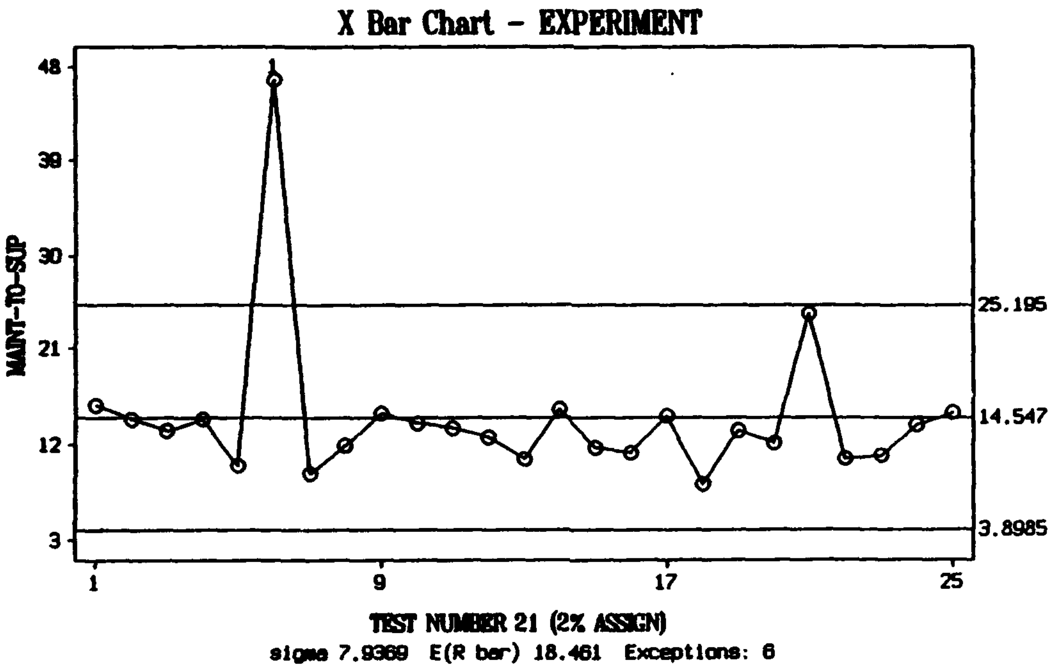


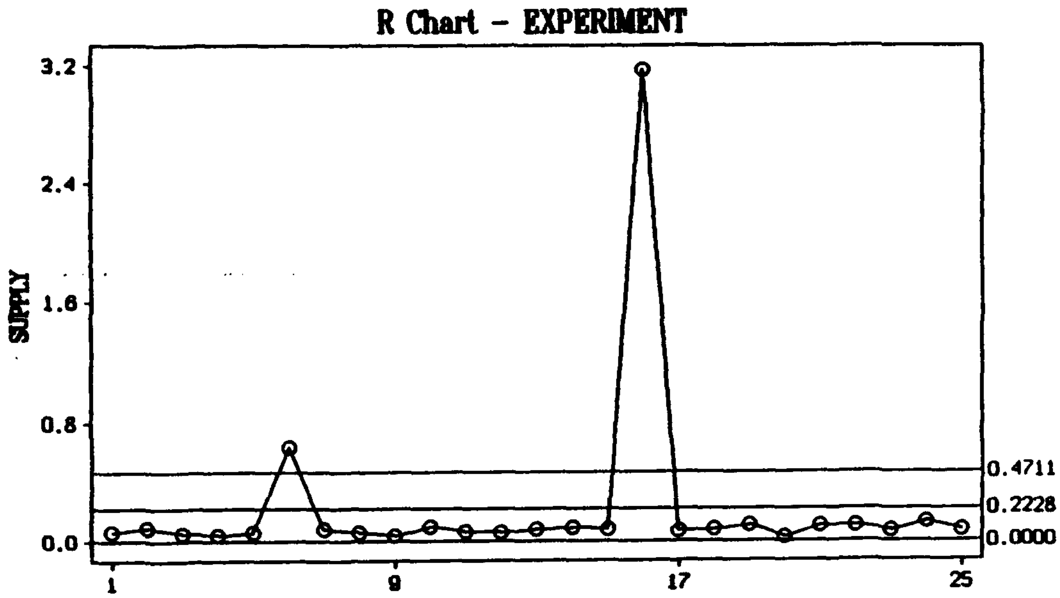
TEST NUMBER 21 (SEGMENT 2% ASSIGN)
sigma 7.9463 E(R bar) 18.483 Exceptions: 6



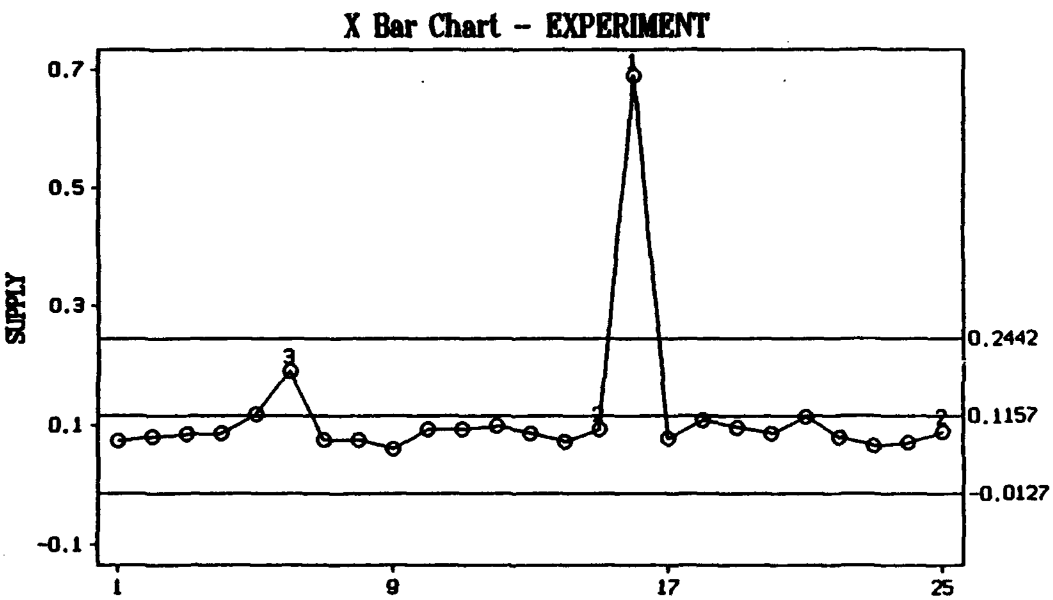
Histogram - EXPERIMENT
Frequency Density
0
20
40
60
80
2
11
20
29
38
47
56
65
74
83
92
101
110
119
128
137
146
155
164
173
TEST NUMBER 21 (SEGMENT)
INTRODUCED 2% ASSIGNABLE


R Chart - EXPERIMENT
160
120
80
40
0
MAINT-TO-SUP
39.033
18.461
0.0000
1
9
17
25
TEST NUMBER 21 (2% ASSIGN)
sigma 7.9369 Exceptions: 6,21

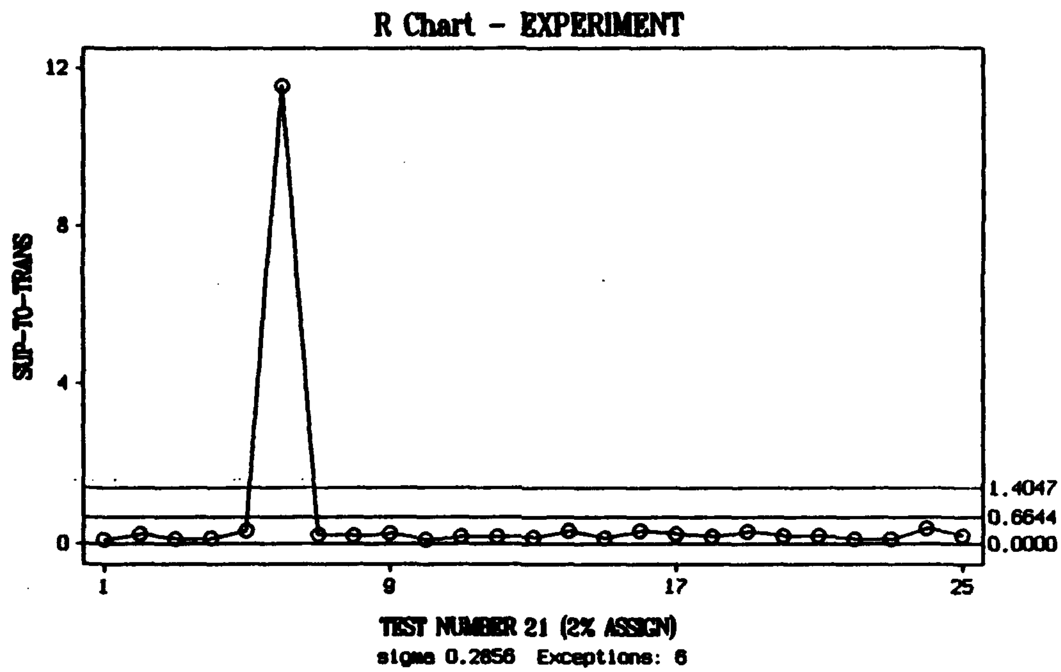

X Bar Chart - EXPERIMENT
48
39
30
21
12
3
MAINT-TO-SUP
25.195
14.547
3.8985
1
9
17
25
TEST NUMBER 21 (2% ASSIGN)
sigma 7.9369 E(R bar) 18.461 Exceptions: 6

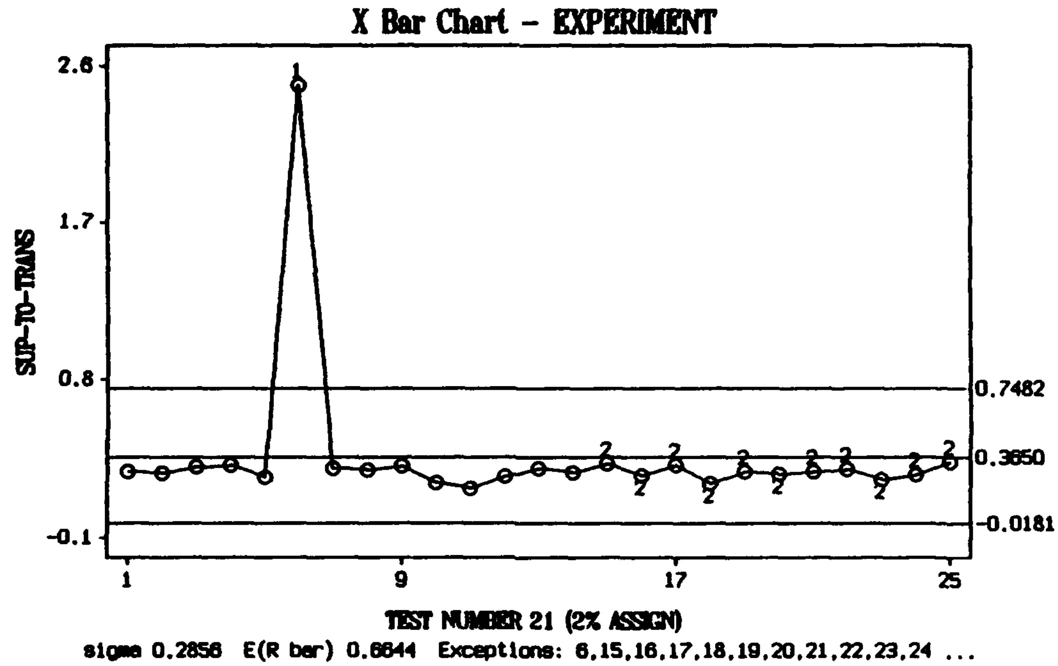


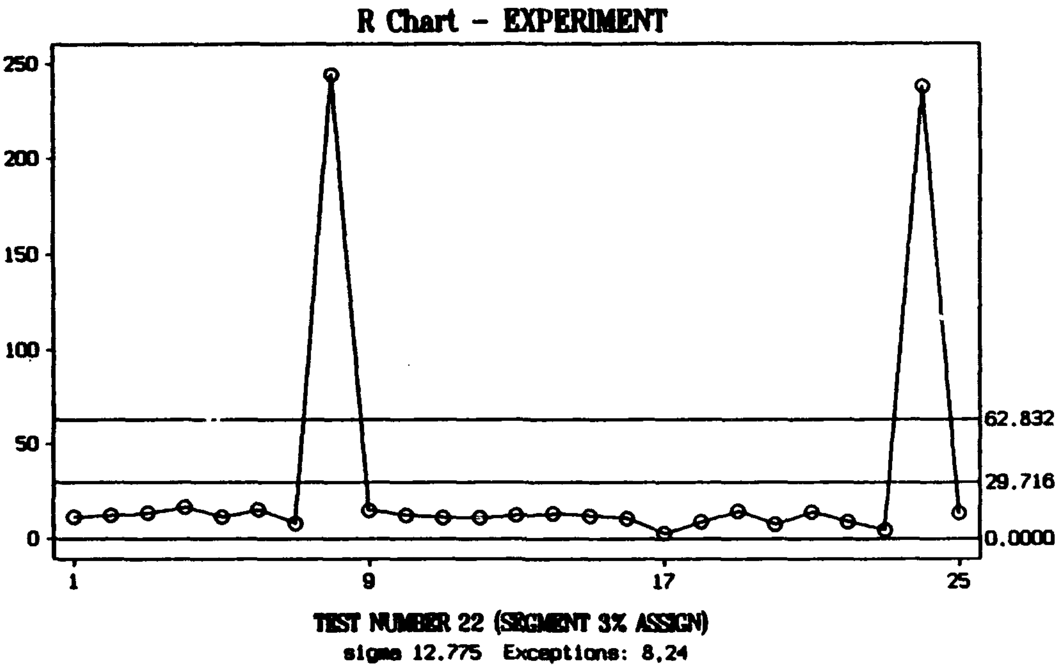
TEST NUMBER 21 (2% ASSIGN)
sigma 0.0958 Exceptions: 6,16



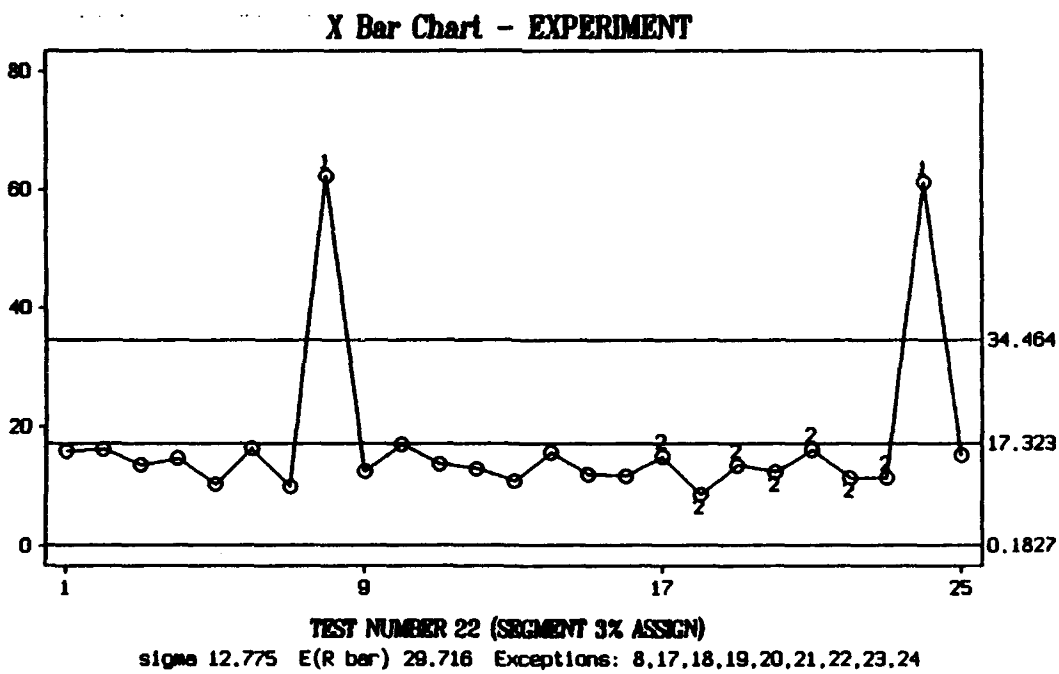
TEST NYMBER 21 (2% ASSIGN)
sigma 0.0958 E(R bar) 0.2228 Exceptions: 6,15,16,25


R Chart - EXPERIMENT
12
8
4
0
SUP-TO-TRANS
1.4047
0.6644
0.0000
1
9
17
25
TEST NUMBER 21 (2% ASSIGN)
sigma 0.2856 Exceptions: 6

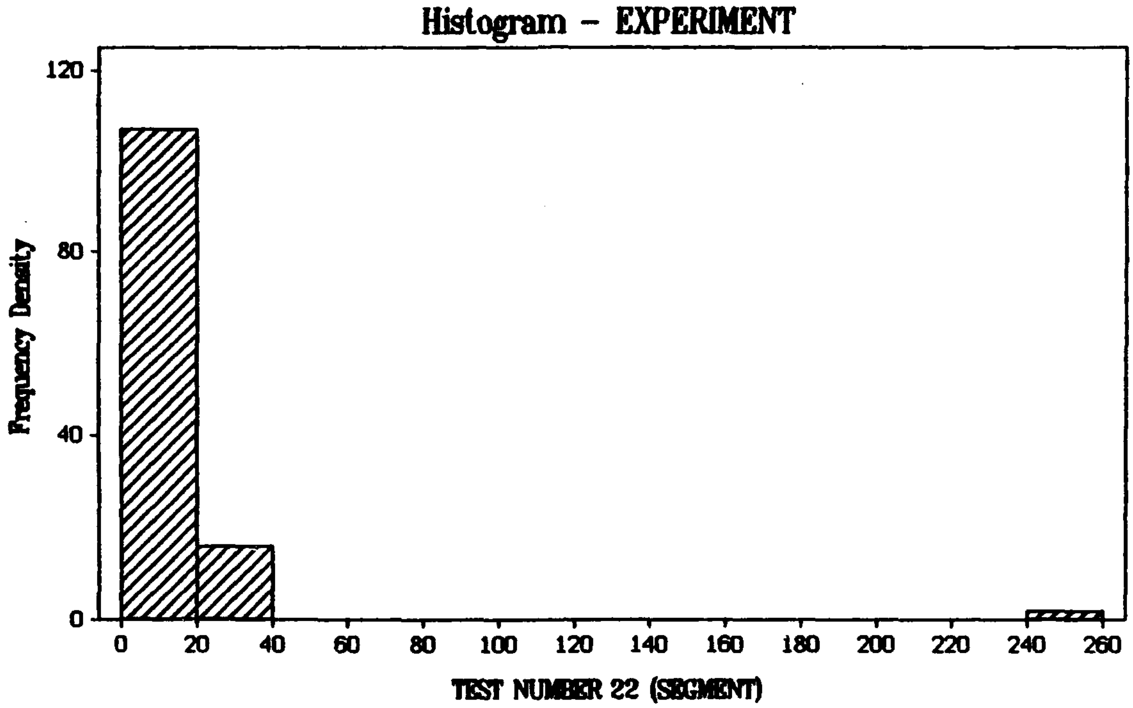

X Bar Chart - EXPERIMENT
2.6
1.7
0.8
-0.1
SUP-TO-TRANS
0.7482
0.3650
-0.0181
1
9
17
25
TEST NUMBER 21 (2% ASSIGN)
sigma 0.2856 E(R bar) 0.6644 Exceptions: 6,15,16,17,18,19,20,21,22,23,24 ...



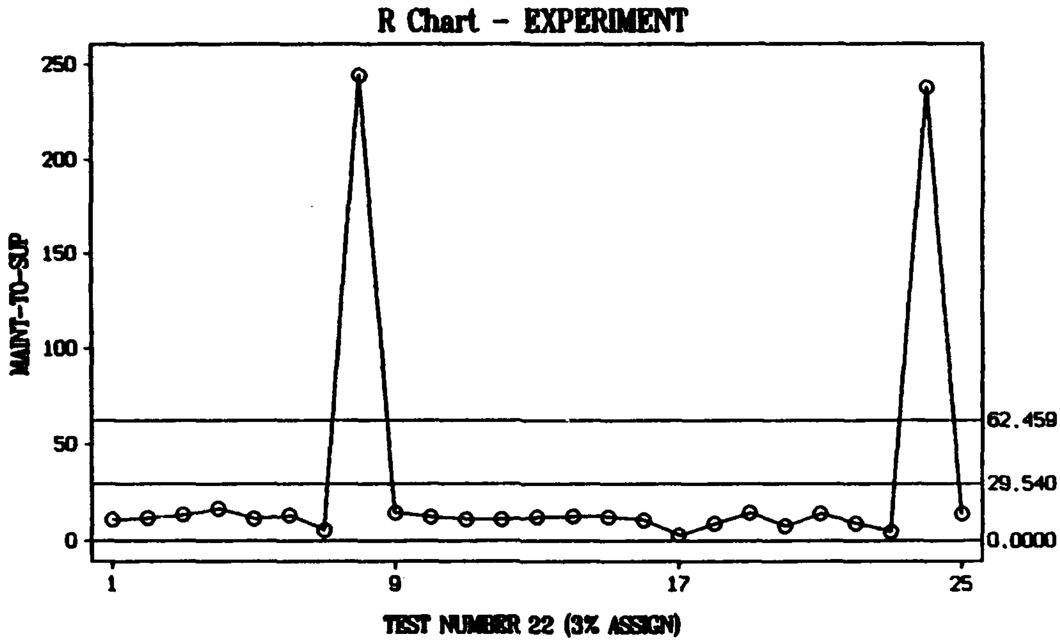
R Chart - EXPERIMENT
250
200
150
100
50
0
62.832
29.716
0.0000
1
9
17
25
TEST NUMBER 22 (SEGMENT 3% ASSIGN)
sigma 12.775 Exceptions: 8,24



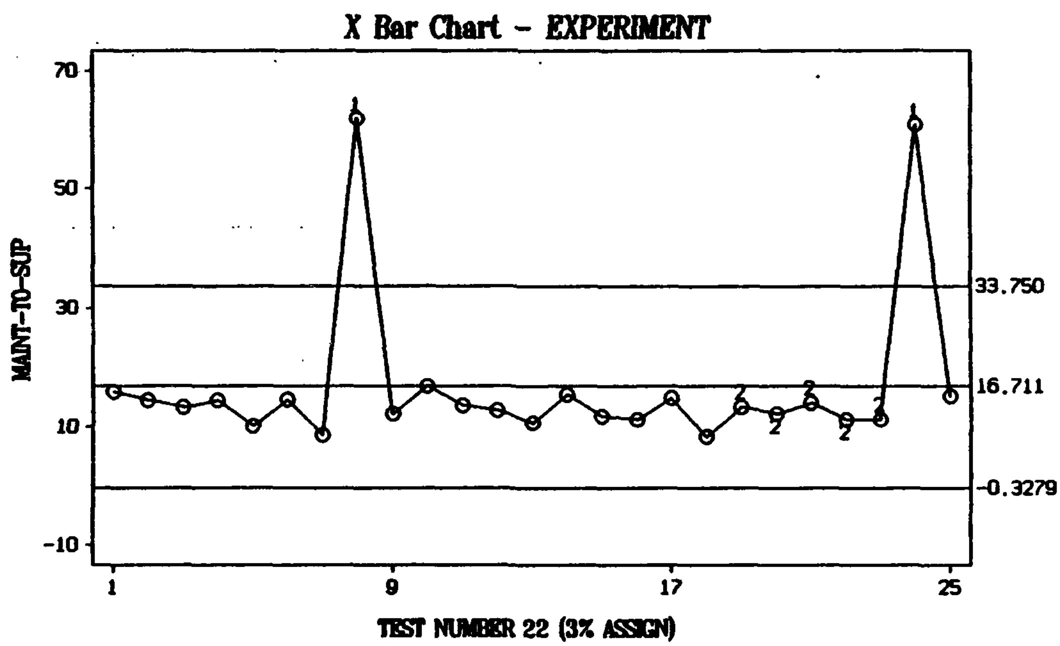
X Bar Chart - EXPERIMENT
80
60
40
20
0
34.464
17.323
0.1827
1
9
17
25
TEST NUMBER 22 (SEGMENT 3% ASSIGN)
sigma 12.775 E(R bar) 29.716 Exceptions: 8,17,18,19,20,21,22,23,24



INTRODUCED 3% ASSIGNABLE

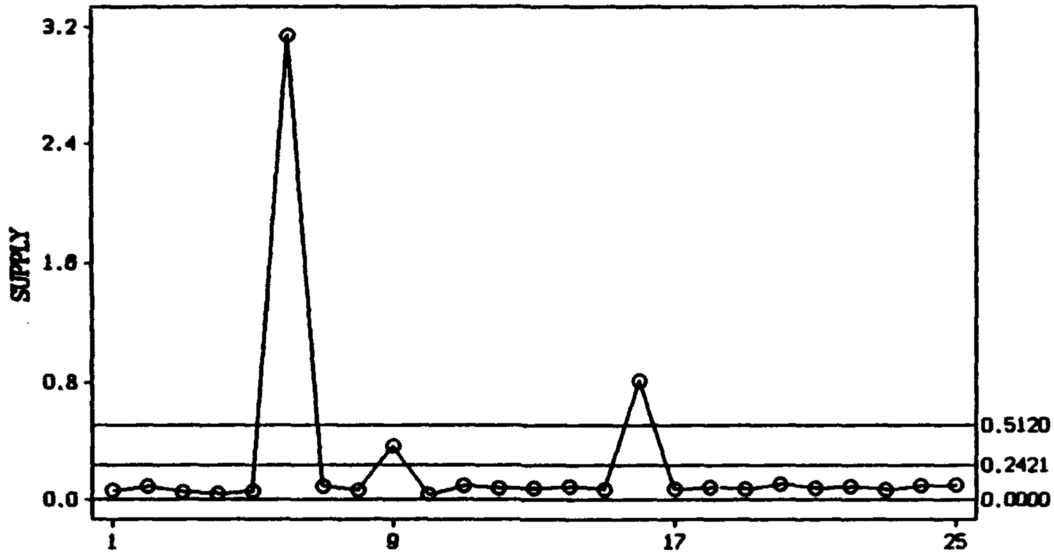


sigma 12.700 Exceptions: 8,24



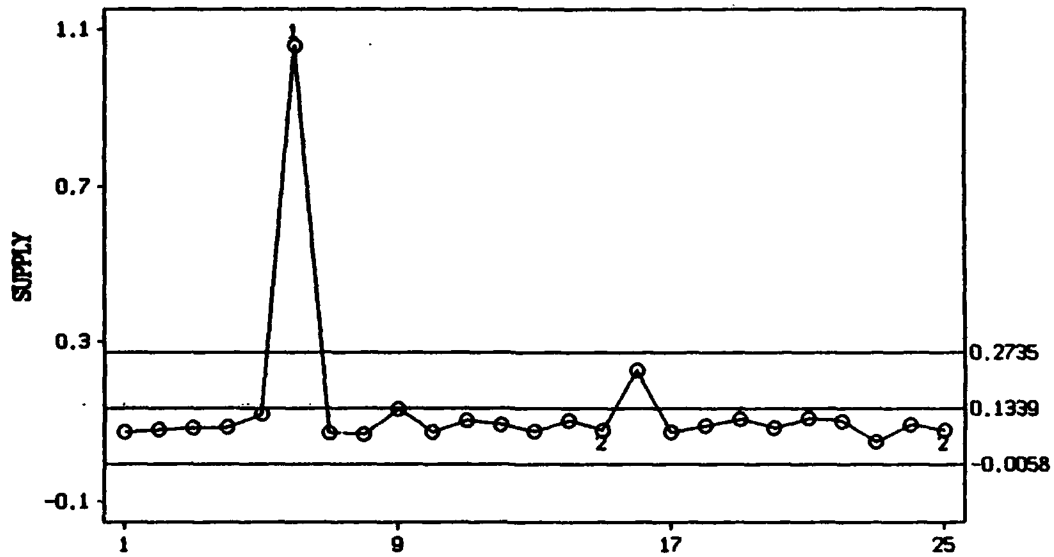
sigma 12.700 E(R bar) 29.540 Exceptions: 8,19,20,21,22,23,24

R Chart - EXPERIMENT

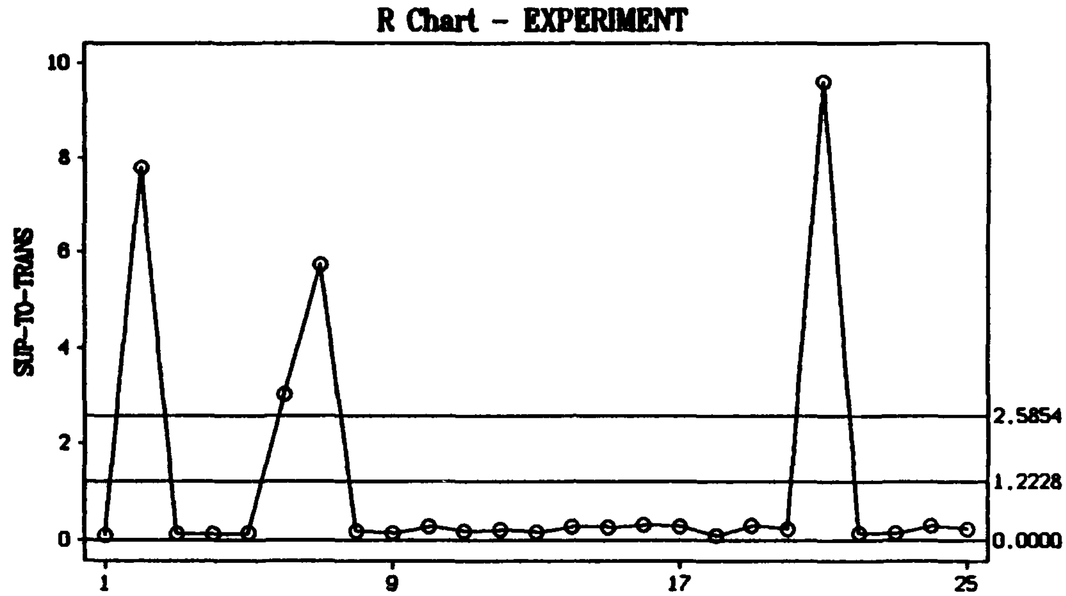


TEST NUMBER 22 (3% ASSIGN)
sigma 0.1041 Exceptions: 6,16

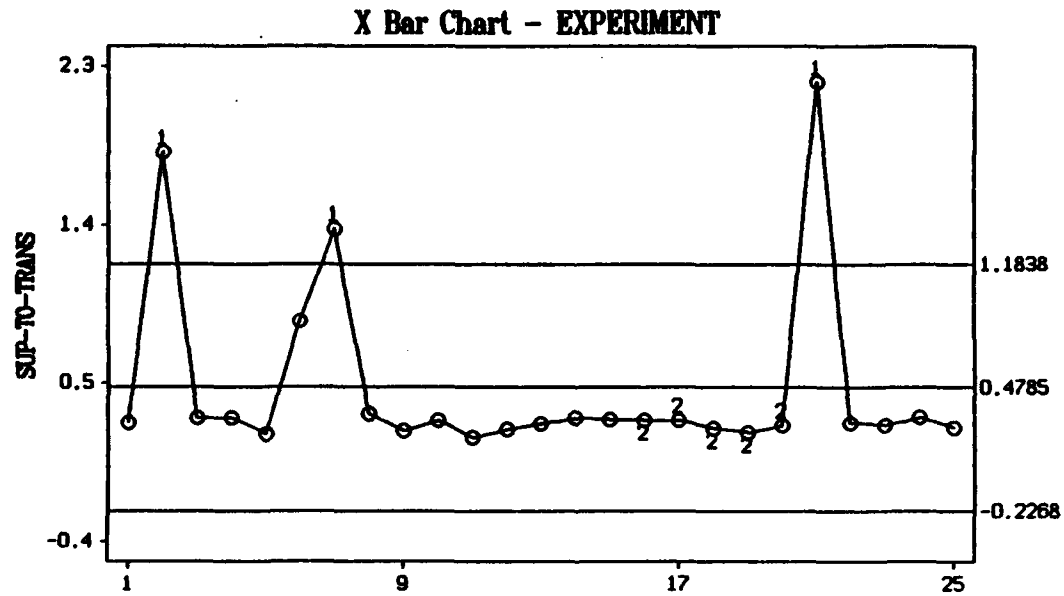
X Bar Chart - EXPERIMENT



TEST NUMBER 22 (3% ASSIGN)
sigma 0.1041 E(R bar) 0.2421 Exceptions: 6,15,25

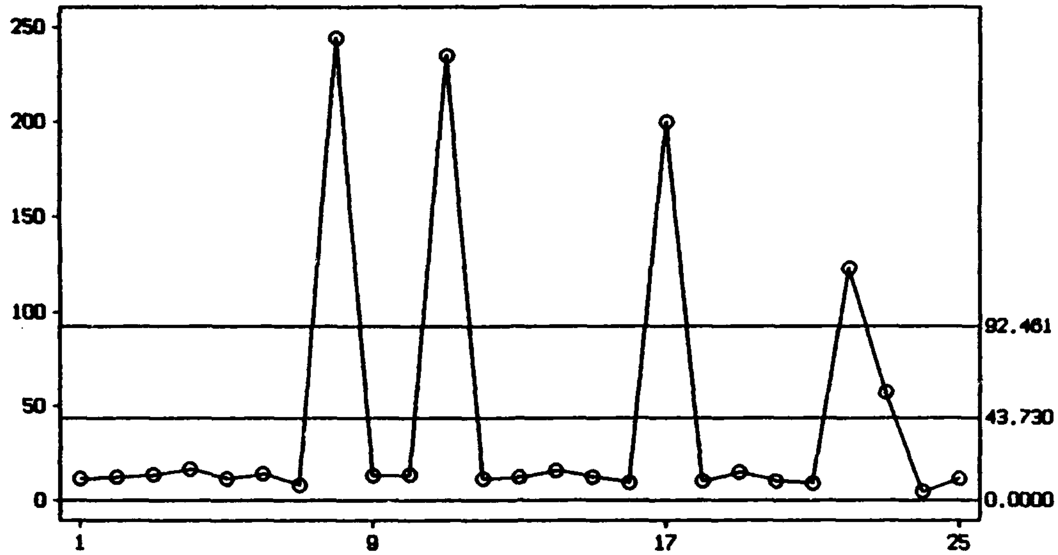


TEST NUMBER 22 (3% ASSIGN)
sigma 0.5257 Exceptions: 2,6,7,21



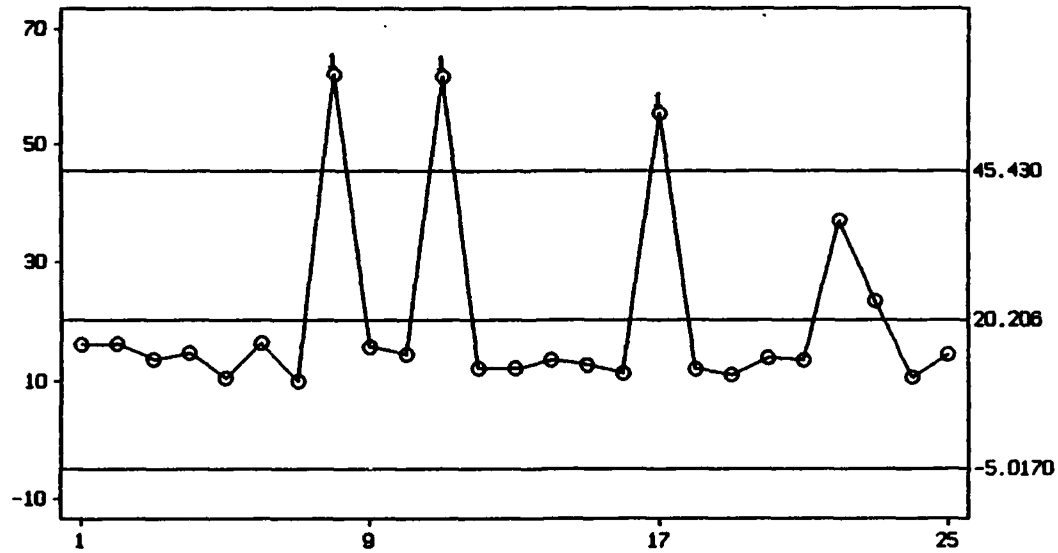
TEST NUMBER 22 (3% ASSIGN)
sigma 0.5257 E(R bar) 1.2228 Exceptions: 2,7,16,17,18,19,20,21

R Chart - EXPERIMENT

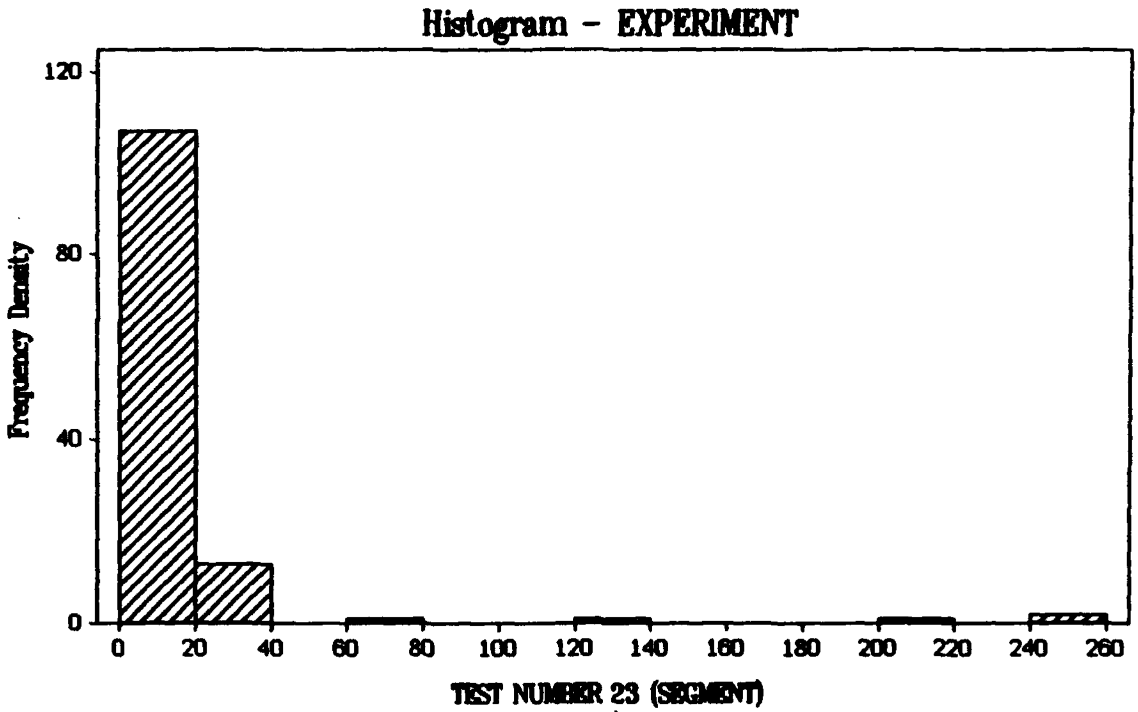


TEST NUMBER 23 (SEGMENT 4% ASSIGN)
sigma 18.800 Exceptions: 8,11,17,22

X Bar Chart - EXPERIMENT

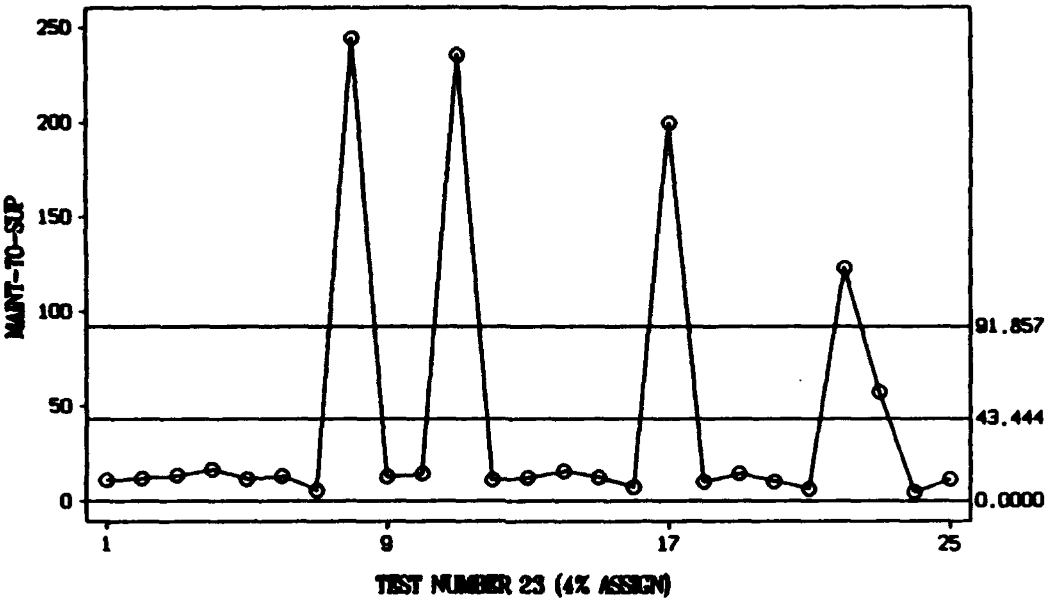


TEST NUMBER 23 (SEGMENT 4% ASSIGN)
sigma 18.800 E(R bar) 43.730 Exceptions: 8,11,17



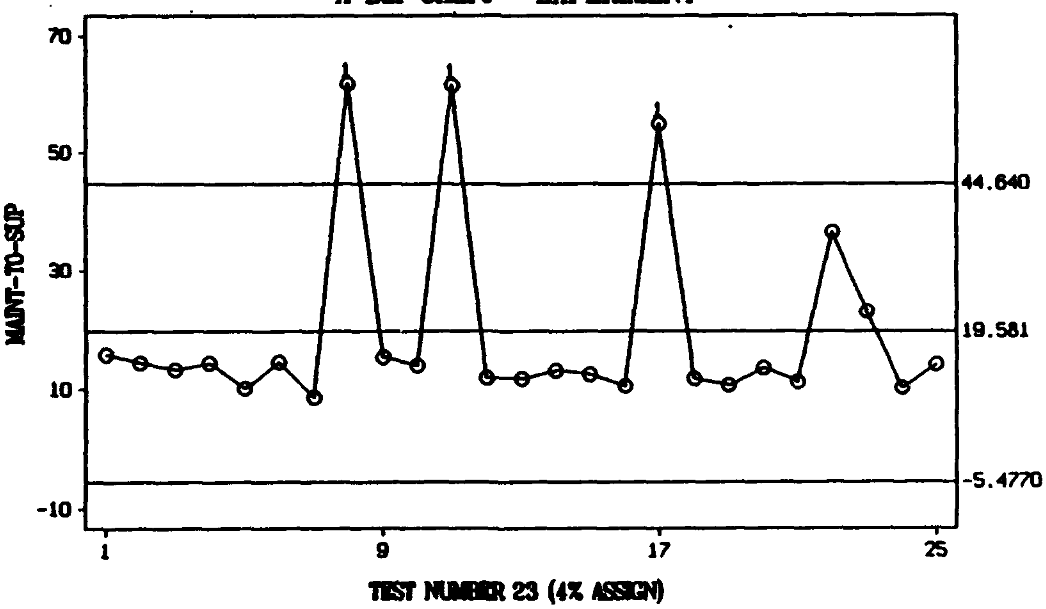
INTRODUCED 4% ASSIGNABLE

R Chart - EXPERIMENT



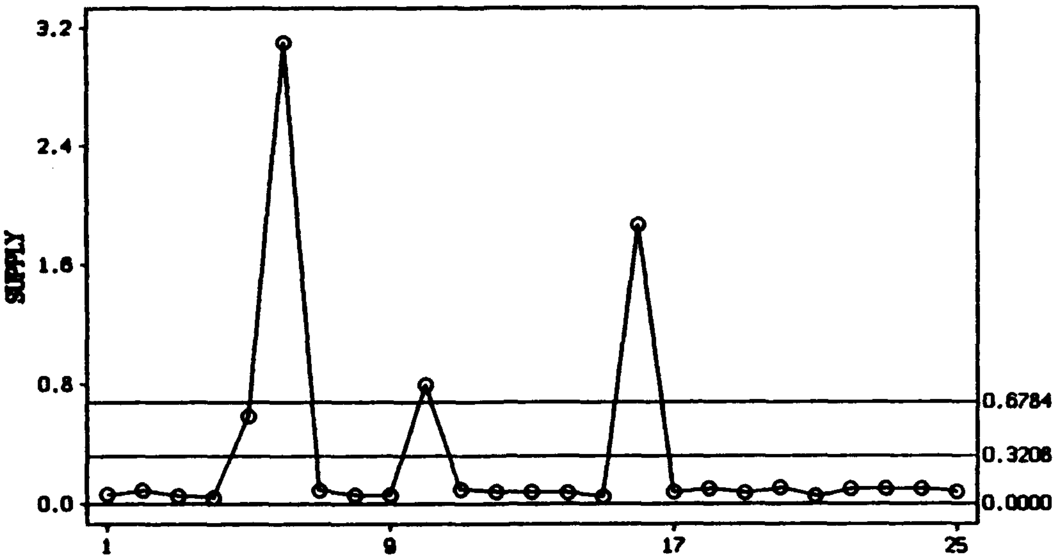
sigma 18.677 Exceptions: 8,11,17,22

X Bar Chart - EXPERIMENT



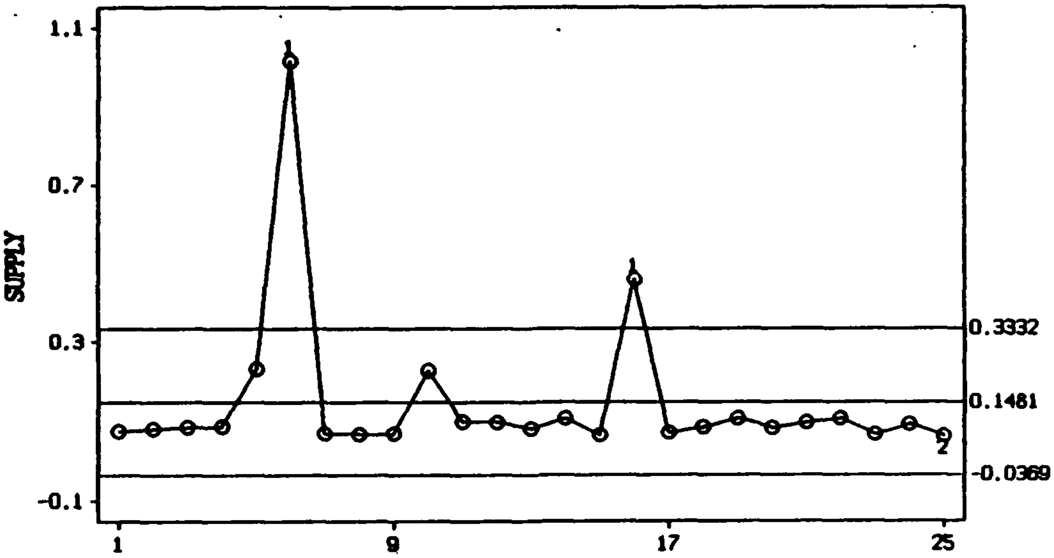
sigma 18.677 E(R bar) 43.444 Exceptions: 8,11,17

R Chart - EXPERIMENT

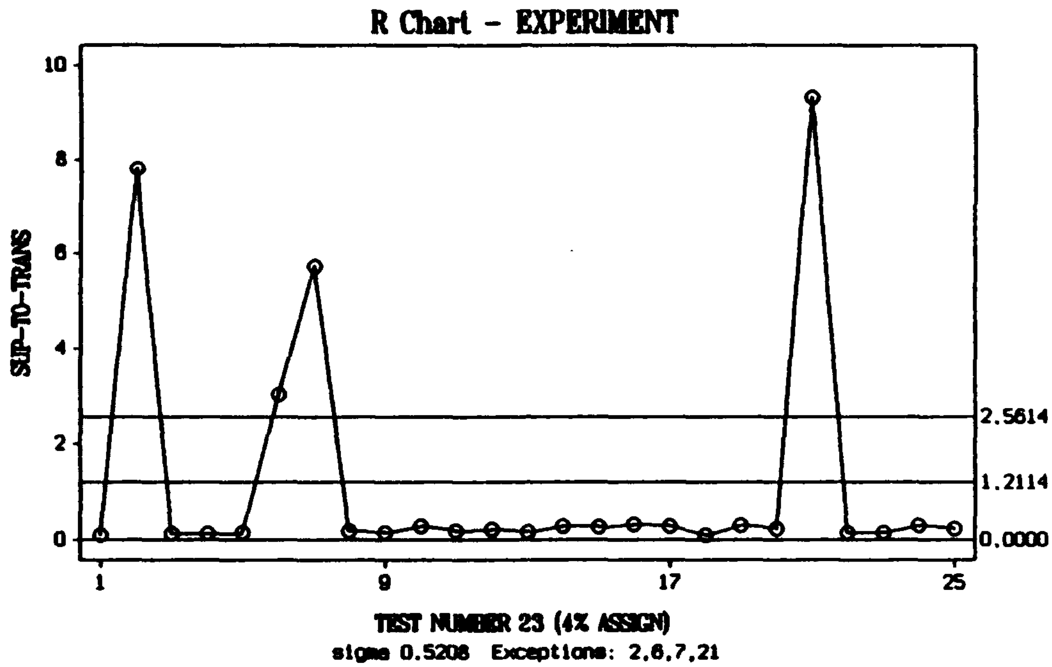


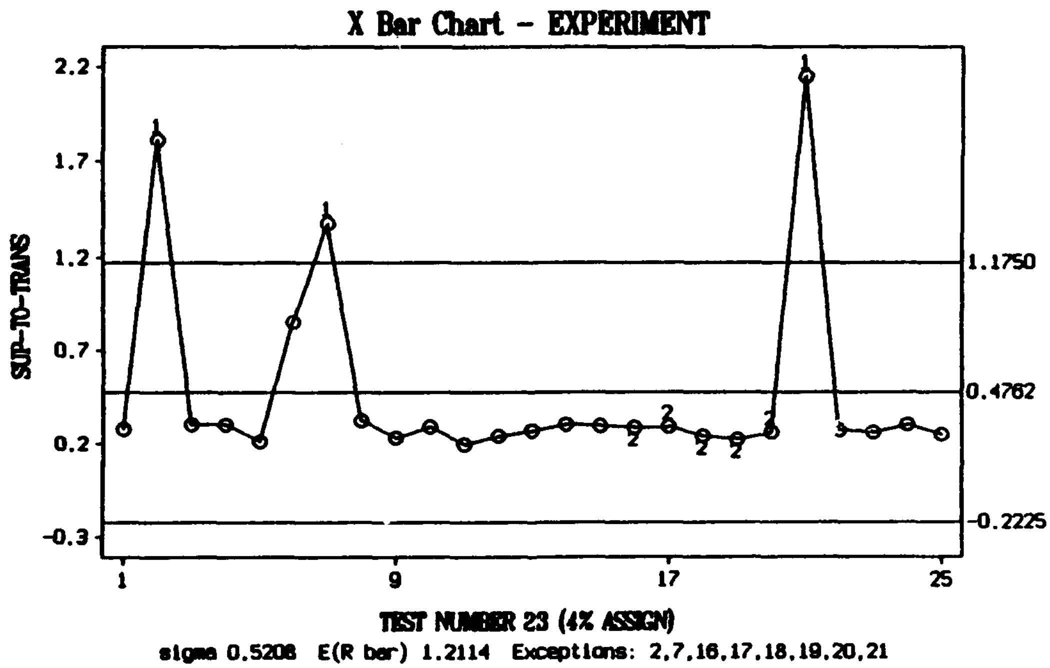
TEST NUMBER 23 (4% ASSIGN)
sigma 0.1379 Exceptions: 6,10,16

X Bar Chart - EXPERIMENT



TEST NUMBER 23 (4% ASSIGN)
sigma 0.1379 E(R bar) 0.3208 Exceptions: 6,16,25


R Chart - EXPERIMENT
SUP-TO-TRANS
10
8
6
4
2
0
2.5614
1.2114
0.0000
1
9
17
25
TEST NUMBER 23 (4% ASSIGN)
sigma 0.5208 Exceptions: 2,6,7,21


X Bar Chart - EXPERIMENT
SUP-TO-TRANS
2.2
1.7
1.2
0.7
0.2
-0.3
1.1750
0.4762
-0.2225
1
9
17
25
TEST NUMBER 23 (4% ASSIGN)
sigma 0.5208 E(R bar) 1.2114 Exceptions: 2,7,16,17,18,19,20,21

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Vita

Captain Harold D. Hites was born on 18 August 1957 in Florence, Alabama. He graduated from Deshler High School in June 1975. He received a Bachelor of Science in Education from Southern Illinois University @ Carbondale in May 1981. He enlisted in the USAF in August 1978 and received a commission in September 1983 from OTS. He was assigned to Detachment 6, 3025 Management Engineering Squadron, Robins AFB Georgia from September 1983 to June 1985. He was assigned to the Directorate of Manpower and Organization, HQ USAFE, Ramstein AB, Germany from June 1985 to June 1988. While at Ramstein, he served as Chief, War Plans Branch. He was assigned to Detachment 11, 4400 Management Engineering Squadron, Mountain Home AFB, Idaho from June 1988 to August 1989. He served as Commander. He was assigned to 366th Supply Squadron, Mountain Home AFB, Idaho from August 1989 to May 1992. He served as Chief, Combat Operations Support Branch and Chief, Materiel Storage and Distribution Branch. He is a graduate of Squadron Officers School. He is married to the former Dru Lynn Foster of Huntsville Alabama, and has a daughter, Michelle. He entered the School of Logistics and Acquisition Management, Air Force Institute of Technology in May 1992.

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13. ABSTRACT *(Maximum 200 words)*
The purpose of this study was to identify and provide pipeline managers with the knowledge and tools necessary for reducing process variation associated with retrograde asset flow time. Several Air Force studies have been devoted to researching portions of the pipeline process. Our study continues this trend of investigations by studying the Base Processing Segment. This study demonstrates the potential for analyzing the Base Processing Segment of the depot-level reparable pipeline using Statistical Process Control. Retrograde asset flow time data collection methods and current management practices were examined. Control charts were used in the passive mode to analyze and determine the statistical stability of the Base Processing Segment. Control charts were used in the active mode in a one-factor experiment that demonstrated the techniques for continuous improvement. Control charting will improve managerial efforts to reduce the flow time of assets through the Base Processing Segment, and ultimately the depot-level reparable pipeline. Elimination of Assignable Causes of variation reduced average flow times by 31 percent. Identifying and eliminating Assignable Causes of variation will immediately improve process performance. The subsequent removal of Common Causes of variation will improve the process.

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5. Comments

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